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FIRES - T3 A COMPUTER PROGRAM FOR THE FIRE RESPONSE OF STRUCTURES -- THERMAL (THREE DIMENSIONAL VERSION)

R. Iding, B. Bresler, and
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United States Department of Commerce
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R. Iding, B. Bresler, and
Z. Nizamuddin

Department of Civil Engineering
University of California, at Berkeley
Berkeley, CA

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Notice

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FIRE RESEARCH GROUP
UNIVERSITY OF CALIFORNIA • BERKELEY

FIRES – T3

A COMPUTER PROGRAM FOR THE FIRE RESPONSE OF STRUCTURES – THERMAL

(THREE-DIMENSIONAL VERSION)

by

R. IDING
B. BRESLER
Z. NIZAMUDDIN

Department of Civil Engineering
Division of Structural Engineering and Structural Mechanics

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FIRES-T3

A Computer Program for the
FIre REsponse of Structures - Thermal
Three - Dimensional Version

by

Robert H. Iding
Zuhayr Nizamuddin
Boris Bresler

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ABSTRACT

This report documents the computer program FIRES-T3 (FIre REsponse of Structures - Thermal - Three-Dimensional Version). The program evaluates the temperature distribution history of general three-dimensional solids or composites such as reinforced concrete subjected to fire environments. There are also options for two-dimensional and one-dimensional heat flow analyses. FIRES-T3 is based on a finite element formulation which considers the temperature dependence of thermal properties and the nonlinearities inherent in modeling the fire boundary condition. The finite element formulation, the idealization of the fire boundary condition, and the general numerical approach used in the program are discussed. Included in the report are appendices that provide input instructions for FIRES-T3, sample problems with listings of their input and output, and a complete Fortran listing of the computer program.

ABSTRACT

This report documents the computer program FIRES-T3 (FIre REsponse of Structures - Thermal - Three-Dimensional Version). The program evaluates the temperature distribution history of general three-dimensional solids or composites such as reinforced concrete subjected to fire environments. There are also options for two-dimensional and one-dimensional heat flow analyses. FIRES-T3 is based on a finite element formulation which considers the temperature dependence of thermal properties and the nonlinearities inherent in modeling the fire boundary condition. The finite element formulation, the idealization of the fire boundary condition, and the general numerical approach used in the program are discussed. Included in the report are appendices that provide input instructions for FIRES-T3, sample problems with listings of their input and output, and a complete Fortran listing of the computer program.

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1. INTRODUCTION

This report presents FIRES-T3, a computer program for the FIre REsponse of Structures - Thermal - Three-Dimensional Version, which evaluates the temperature distribution history of structures in fire environments. There are options for fully three-dimensional solids, two-dimensional cross-sections, and structures in which heat flow is one-dimensional. The program also permits the use of one-, two-, and three-dimensional elements together in the same structure. Structures may consist of one material or may be composites such as reinforced concrete. The temperature distributions generated by FIRES-T3 can be used in conjunction with stress analysis programs such as FIRES-RC II (a computer program for the response of Reinforced Concrete Frames [6]) or FIRES-SL (a computer program for the response of SLabs [7]), together providing an overall capability of predicting the response of structures subjected to fires.

The heat flow problem is modeled in FIRES-T3 by the heat conduction boundary value problem. These equations are nonlinear because of the temperature dependence of the thermal properties of structural materials and the heat transfer mechanisms associated with fire environments. The solution technique used in FIRE-T3 is a finite element method coupled with time step integration. This general approach has been presented in the work of Wilson [10,11] and Zienkiewicz [12,13] and extended to the fire situation by Bizri [3]. The nonlinearity of the problem requires an iterative solution process within each step. The element library includes isoparametric 8-node hexahedra and 4-node tetrahedra for three-dimensional solids, 4-node isoparametric quadrilaterals and triangles for two-dimensional modeling, and 2-node isoparametric bar elements for one-dimensional problems. Fire environments are represented by a linear model or a nonlinear model that includes both convective and radiative mechanisms.

In the report, the theoretical model and solution techniques are derived, the organization of the computer program is explained, and a commentary on practical aspects of using the program is made. The appendices contain fully annotated input instructions, sample problems with input and output, and a Fortran listing of the program.

2. THERMAL MODEL AND SOLUTION PROCEDURE

2.1 Heat Flow Equations

Three dimensional heat flow is governed by the following partial differential equation:

$$\rho C_p \frac{\partial T(x, y, z, t)}{\partial t} = \frac{\partial}{\partial x}\left(K \frac{\partial T(x, y, z, t)}{\partial x}\right) + \frac{\partial}{\partial y}\left(K \frac{\partial T(x, y, z, t)}{\partial y}\right) +$$

$$\frac{\partial}{\partial z}\left(K \frac{\partial T(x, y, z, t)}{\partial z}\right) + Q_{exo}(x, y, z, t) \tag{2.1}$$

where

x, y, z	-	spatial coordinates
t	-	time
$T(x, y, z, t)$	-	temperature distribution history
ρ	-	density (temperature- and space-dependent)
C_p	-	specific heat (temperature- and space-dependent)
K	-	isotropic conductivity (temperature- and space-dependent)
Q_{exo}	-	internal heat generation rate (time- and space-dependent)

An integral part of the above equation is its boundary conditions and initial conditions. The initial conditions consist of the temperature of every point in the structure when the analysis begins, i.e.,

$$T(x, y, z, t_o) = T_o(x, y, z) \tag{2.2}$$

where the temperature distribution T_o is specified. Boundary conditions must be defined at every point on the structure's surface and can be a specified temperature history or a specified heat flow history. The solution to the heat flow problem is the internal temperature history that satisfies the field equations (2.1), the initial conditions (2.2), and the prescribed boundary conditions.

For the special case of two-dimensional heat flow, the governing equations are

$$\rho C_p \frac{\partial T(x, y, t)}{\partial t} = \frac{\partial}{\partial x} \left(K \frac{\partial T(x, y, t)}{\partial x}\right) + \frac{\partial}{\partial y} \left(K \frac{\partial T(x, y, t)}{\partial y}\right) + Q_{exo}(x, y, t) \quad (2.3)$$

with appropriate boundary conditions and initial conditions defined over a two-dimensional area.

One-dimensional heat flow is governed by the equation

$$\rho C_p \frac{\partial T(x, t)}{\partial t} = \frac{\partial}{\partial x} \left(K \frac{\partial T(x, t)}{\partial x}\right) + Q_{exo}(x, t) \quad (2.4)$$

Boundary conditions are defined by specifying a flow rate or temperature at each end of the one-dimensional domain.

2.2 Finite Element Matrix Equations

The heat flow equations for two- and three-dimensional bodies described above are very complex and in almost all cases have no closed-form solution; approximate numerical methods must be used in order to obtain a solution. In program FIRES-T3, a finite element method discretizes spacial variables and a step-by-step integration technique discretizes the time variable. The advantages of the finite element method are numerous. The method is completely general with respect to geometry and material properties; complex shapes composed of different materials (e.g. a reinforced concrete structure) are easily represented. Nonlinearity of material and boundary conditions can be treated by the finite element method quite economically. Most numerical methods convert the continuous governing differential or integral equations of heat transfer to a set of linear algebraic equations. However, in the finite element method, the linear equations produce a symmetric positive-definite matrix in banded form which is readily solved with a minimum of computer storage and time.

In the finite element method, the continuum over which Eq. (2.1) or Eq. (2.3) is defined is discretized into a finite number of elements connected at nodal points. The complex partial differential equation is transformed into a system of simultaneous first order differential equations, one at each node. This transformation is effected element by element as explained in the next three sections. The system of nodal equations is then solved by step-by-step integration over the time domain, as explained in Section 2.6.

The finite element equations can be visualized physically as nodal heat balance equations. That is, at each node in the discretization,

$$Q^s + Q^i = Q^e \tag{2.5}$$

where

Q^s = rate at which heat is stored within the elements adjacent to node; in steady state conditions, this term is zero at all nodes

Q^i = rate of internal heat transfer by conduction in the elements adjacent to the node

Q^e = rate at which heat enters the node from an external source

or, in matrix form,

$$[C]\{\dot{T}\} + [K]\{T\} = \{Q\} \tag{2.6}$$

where

[C] = Capacity matrix (temperature-dependent)

[K] = Conductivity matrix (temperature-dependent)

{Q} = External heat flow vector (depends on exothermic reactions and fire boundary conditions)

{T} = Temperature vector (time-dependent)

$\{\dot{T}\}$ = Temperature time rate of change vector (time-dependent)

The derivation of the three terms of this equation (conductivity matrix, capacity matrix, and heat flow vector) are discussed in the next three sections.

2.3 Conductivity Matrix [K]

The terms of the conductivity matrix are associated with the rate of heat flow from the elements adjacent to each node. The conductivity matrix for the system being analyzed, $\underline{K}$, is assembled from element conductivity matrices, $\underline{K_m}$. That is:

$$\underline{K} = \sum_{m=1}^{M} \underline{K_m} \tag{2.7}$$

where m is the element number and M is the total number of elements. The development of the conductivity matrices for three-dimensional, two-dimensional, and one-dimensional isoparametric finite elements is presented below. Three-dimensional elements can be used only for a three-dimensional analysis. Two-dimensional elements can be used in a two-dimensional analysis or as a component in a three-dimensional analysis. The one-dimensional elements can be used in conjunction with two- and three-dimensional elements in a multidimensional analysis or by themselves to model one-dimensional heat flow.

2.3.1 Three-Dimensional Isoparametric Element

This element is called isoparametric because the geometry of the element and the assumed temperature distribution within the element are described in terms of the same ("iso") parameters (or shape functions) and are of the same order (linear in this case).

An eight node three-dimensional isoparametric element is shown in Fig. 2.1. The natural coordinates ($\bar{x}$, $\bar{y}$, $\bar{z}$) of the eight corner nodes are (±1, ±1, ±1). A natural coordinate system is a local system which permits the specification of a point within the element by a set of

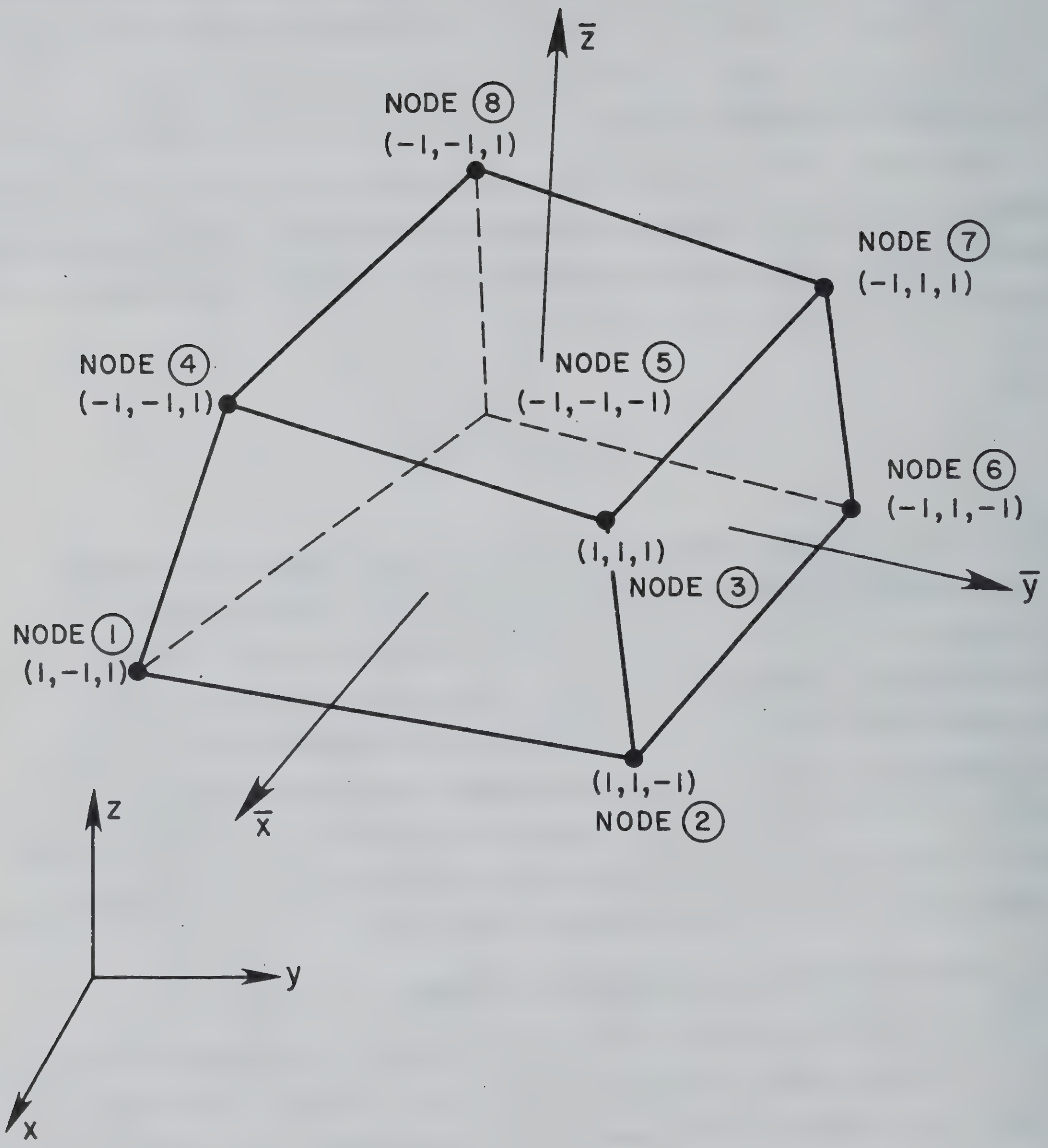

FIGURE 2.1 THREE-DIMENSIONAL ISOPARAMETRIC ELEMENT

dimensionless numbers whose magnitudes never exceed unity. This system is usually arranged so that the natural coordinates have unit magnitude at the nodal points of the element. Such a system simplifies the formulation and facilitates the numerical integration which is required to obtain element matrices. The symbols x, y, and z denote the global coordinate axes.

The temperature at any point within the element is expressed in the natural coordinate system $(\bar{x}, \bar{y}, \bar{z})$ in terms of the temperatures at nodes 1 to 8 by the following equation:

$$T(\bar{x}, \bar{y}, \bar{z}, t) = \sum_{i=1}^{8} H_i(\bar{x}, \bar{y}, \bar{z}) \cdot T_i(t) \qquad (2.8a)$$

or, in matrix form:

$$\underset{1 \times 1}{T(\bar{x}, \bar{y}, \bar{z}, t)} = \underset{1 \times 8}{< H_i >} \; \underset{8 \times 1}{\{T_i\}} \qquad (2.8b)$$

where

$$H_i(\bar{x}, \bar{y}, \bar{z}) = \frac{1}{8} (1 + \bar{x}\,\bar{x}_i)(1 + \bar{y}\,\bar{y}_i)(1 + \bar{z}\,\bar{z}_i) \qquad (2.9)$$

(linear interpolation function)

$\bar{x}_i, \bar{y}_i, \bar{z}_i$ - natural coordinates of node i (either 1 or -1)

$T_i(t)$ - temperature of node i

$< H_i >$ = $< H_1 \; H_2 \; . \; . \; . \; . \; H_8 >$

$\{T_i\}$ - column vector of nodal point temperatures

Similarly, the global coordinates of any point within the element are related to the global coordinates of the nodal points by the following equation:

$$\underset{3 \times 1}{\begin{Bmatrix} x \\ y \\ z \end{Bmatrix}} = \underset{3 \times 24}{\begin{bmatrix} < H_i > & 0 & 0 \\ 0 & < H_i > & 0 \\ 0 & 0 & < H_i > \end{bmatrix}} \underset{24 \times 1}{\begin{Bmatrix} \{x_i\} \\ \{y_i\} \\ \{z_i\} \end{Bmatrix}} \qquad (2.10)$$

where

$$\{x_i\}^T = < x_1 \; x_2 \; . \; . \; . \; . \; . \; x_8 >$$

$$\{y_i\}^T = < y_1 \; y_2 \; . \; . \; . \; . \; . \; y_8 >$$

$$\{z_i\}^T = < z_1 \; z_2 \; . \; . \; . \; . \; . \; z_8 >$$

are the nodal point coordinates in global system.

When calculating the element conductivity matrix, an expression for temperature gradient within the element is needed. Differentiation of Eq. (2.8) with respect to spatial coordinates yields:

$$\underset{3 \times 1}{\begin{Bmatrix} \frac{\partial T}{\partial x} \\ \frac{\partial T}{\partial y} \\ \frac{\partial T}{\partial z} \end{Bmatrix}} = \underset{3 \times 8}{\begin{bmatrix} < \frac{\partial H_i}{\partial x} > \\ < \frac{\partial H_i}{\partial y} > \\ < \frac{\partial H_i}{\partial z} > \end{bmatrix}} \underset{8 \times 1}{\{T_i\}} = [B]\,\{T_i\} \tag{2.11}$$

The spatial derivatives in the natural and global coordinate systems are related by the following equation (using the chain rule of differentiation).

$$\underset{3 \times 1}{\begin{Bmatrix} \frac{\partial}{\partial \bar{x}} \\ \frac{\partial}{\partial \bar{y}} \\ \frac{\partial}{\partial \bar{z}} \end{Bmatrix}} = \underset{3 \times 3}{[J]} \underset{3 \times 1}{\begin{Bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{Bmatrix}} \tag{2.12}$$

where

$$[J] = \begin{bmatrix} \frac{\partial x}{\partial \bar{x}} & \frac{\partial y}{\partial \bar{x}} & \frac{\partial z}{\partial \bar{x}} \\ \frac{\partial x}{\partial \bar{y}} & \frac{\partial y}{\partial \bar{y}} & \frac{\partial z}{\partial \bar{y}} \\ \frac{\partial x}{\partial \bar{z}} & \frac{\partial y}{\partial \bar{z}} & \frac{\partial z}{\partial \bar{z}} \end{bmatrix} \tag{2.13}$$

is the Jacobian matrix. From Eq. (2.10) it can be shown that:

$$[J] = \underset{3 \times 8}{\begin{bmatrix} \frac{\partial H_1}{\partial \bar{x}} & \frac{\partial H_2}{\partial \bar{x}} & \cdots\cdots & \frac{\partial H_8}{\partial \bar{x}} \\ \frac{\partial H_1}{\partial \bar{y}} & \frac{\partial H_2}{\partial \bar{y}} & \cdots\cdots & \frac{\partial H_8}{\partial \bar{y}} \\ \frac{\partial H_1}{\partial \bar{z}} & \frac{\partial H_2}{\partial \bar{z}} & \cdots\cdots & \frac{\partial H_8}{\partial \bar{z}} \end{bmatrix}} \underset{8 \times 3}{\begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ x_8 & y_8 & z_8 \end{bmatrix}} \tag{2.14}$$

Finally, using Eq. (2.12) in Eq. (2.11), one obtains

$$[B] = \underset{3 \times 8}{\begin{bmatrix} < \frac{\partial H_i}{\partial x} > \\ < \frac{\partial H_i}{\partial y} > \\ < \frac{\partial H_i}{\partial z} > \end{bmatrix}} = \underset{3 \times 3}{[J]^{-1}} \underset{3 \times 8}{\begin{bmatrix} < \frac{\partial H_i}{\partial \bar{x}} > \\ < \frac{\partial H_i}{\partial \bar{y}} > \\ < \frac{\partial H_i}{\partial \bar{z}} > \end{bmatrix}} \tag{2.15}$$

Using the virtual work principle, it can be shown that the element conductivity matrix is given by [12]

$$\underset{8x8}{\underline{K_m}} = \int_{Vol.} \underset{8x3}{\underline{B}^T} \; \underset{3x3}{\underline{k_m}} \; \underset{3x8}{\underline{B}} \; dv \tag{2.16}$$

in which $\underline{k_m}$ is the material thermal conductivity tensor of the element. For isotropic conductivity, the above equation reduces to

$$\underset{8x8}{\underline{K_m}} = \int_{Vol.} k_m \; \underset{8x3}{\underline{B}^T} \; \underset{3x8}{\underline{B}} \; dv \tag{2.17}$$

Note that [12]

$$dv = dx \cdot dy \cdot dz = |J| \; d\bar{x} \cdot d\bar{y} \cdot d\bar{z} \tag{2.18}$$

where $|J|$ is the Jacobian (determinant of [J]). By making a change in coordinates to the natural coordinate system, Eq. (2.17) becomes:

$$\underset{8x8}{\underline{K_m}} = \int_{-1}^{+1}\int_{-1}^{+1}\int_{-1}^{+1} k_m \; \underset{8x3}{\underline{B}^T} \; \underset{3x8}{\underline{B}} \; |J| \; d\bar{x} \; d\bar{y} \; d\bar{z} \tag{2.19}$$

If k_m is constant throughout the element, the above integral reduces to

$$\underset{8x8}{\underline{K_m}} = k_m \int_{-1}^{+1}\int_{-1}^{+1}\int_{-1}^{+1} \underset{8x8}{\underline{f}} \, (\bar{x}, \bar{y}, \bar{z}) \; d\bar{x} \; d\bar{y} \; d\bar{z} \tag{2.20}$$

where

$$\underset{8x8}{\underline{f}} \; (\bar{x}, \bar{y}, \bar{z}) = \underset{8x3}{\underline{B}^T} \; \underset{3x8}{\underline{B}} \; |J|$$

It is impractical to integrate expression (2.20) in closed form, and approximate numerical integration methods must be used [11,12]. Although there are several numerical integration schemes available, Gauss quadrature is used in FIRES-T3. Using Gauss' Formula, expression (2.20) is evaluated as follows:

$$\int_{-1}^{+1}\int_{-1}^{+1}\int_{-1}^{+1} \underset{8\times 8}{\underline{f}} (\bar{x}, \bar{y}, \bar{z})\, d\bar{x}\, d\bar{y}\, d\bar{z} = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{n=1}^{N} W_i \; W_j \; W_n \; \underset{8\times 8}{\underline{f}} (\bar{x}_i, \bar{y}_j, \bar{z}_n) \tag{2.22}$$

where

I, J, N - number of integration points in directions $\bar{x}, \bar{y}, \bar{z}$, respectively

$\bar{x}_i, \bar{y}_j, \bar{z}_n$ - coordinates of integration points

W_i, W_j, W_n - weight functions

Values of the coordinates and weight functions for various values of the number of integration points are tabulated in Reference 12 and in other texts on numerical methods. In FIRES-T3 the number of integration points is taken equal to two in each direction, yielding a total of eight integration points within the element. That is:

$$I = J = N = 2$$

Then, from appropriate tables [12], it is found that

$$\bar{x}_i, \bar{y}_j, \bar{z}_n = \pm \frac{\sqrt{3}}{3}, \pm \frac{\sqrt{3}}{3}, \pm \frac{\sqrt{3}}{3}$$

and

$$W_i, W_j, W_n = 1, 1, 1$$

The computational scheme proceeds as follows. First, the spatial derivatives of $< H_i >$ are evaluated at integration point $(\bar{x}_i, \bar{y}_j, \bar{z}_n)$.

Then these derivatives are used in Eq. (2.14), along with the known global coordinates, $(x_1, \ldots, x_8)$, $(y_1, \ldots, y_8)$ and $(z_1, \ldots, z_8)$ of the element corners, to obtain the Jacobian matrix $\underline{J}(\bar{x}_i, \bar{y}_j, \bar{z}_n)$ at point $(\bar{x}_i, \bar{y}_j, \bar{z}_n)$. This matrix is inverted and used in Eq. (2.15), along with the spatial derivatives of $< H_i >$ at point $(\bar{x}_i, \bar{y}_j, \bar{z}_n)$, to obtain the matrix $\underline{B}(\bar{x}_i, \bar{y}_j, \bar{z}_n)$. Finally, the determinant of the Jacobian $|\underline{J}(\bar{x}_i, \bar{y}_j, \bar{z}_n)|$ is calculated and used together with $\underline{B}(\bar{x}_i, \bar{y}_j, \bar{z}_n)$ in Eq. (2.21) to obtain:

$$\underset{8\text{x}8}{\underline{f}} (\bar{x}_i, \bar{y}_j, \bar{z}_n) = \underset{8\text{x}3}{\underline{B}^T} (\bar{x}_i, \bar{y}_j, \bar{z}_n)\ \underset{3\text{x}8}{\underline{B}} (\bar{x}_i, \bar{y}_j, \bar{z}_n)\ |\underline{J} (\bar{x}_i, \bar{y}_j, \bar{z}_n)| \quad (2.23)$$

Equation (2.23) is evaluated at the eight integration points and added in Eq. (2.22) to get a total value for the integral. Substitution into Eq. (2.20) completes the derivation of element conductivity.

2.3.2 Two-Dimensional Isoparametric Element

The two-dimensional isoparametric element is very similar to the three-dimensional element, so the derivation below is brief to avoid redundancy.

A typical four node two-dimensional isoparametric element is shown in Fig. 2.2. The natural coordinates $(\bar{x}, \bar{y})$ of the four corner nodes are $(\pm 1, \pm 1)$. Global coordinates are denoted by x and y.

The temperature at any point within the element is expressed in the natural coordinate system $(\bar{x}, \bar{y})$ in terms of the temperatures at nodes 1 to 4 by the following equation:

$$T(\bar{x}, \bar{y}, t) = \sum_{i=1}^{4} H_i(x, y) \cdot T_i(t) \quad (2.24a)$$

or, in matrix form

$$\underset{1 \times 1}{T(\bar{x}, \bar{y}, t)} = \underset{1 \times 4}{< H_i >}\ \underset{4 \times 1}{\{T_i\}} \quad (2.24b)$$

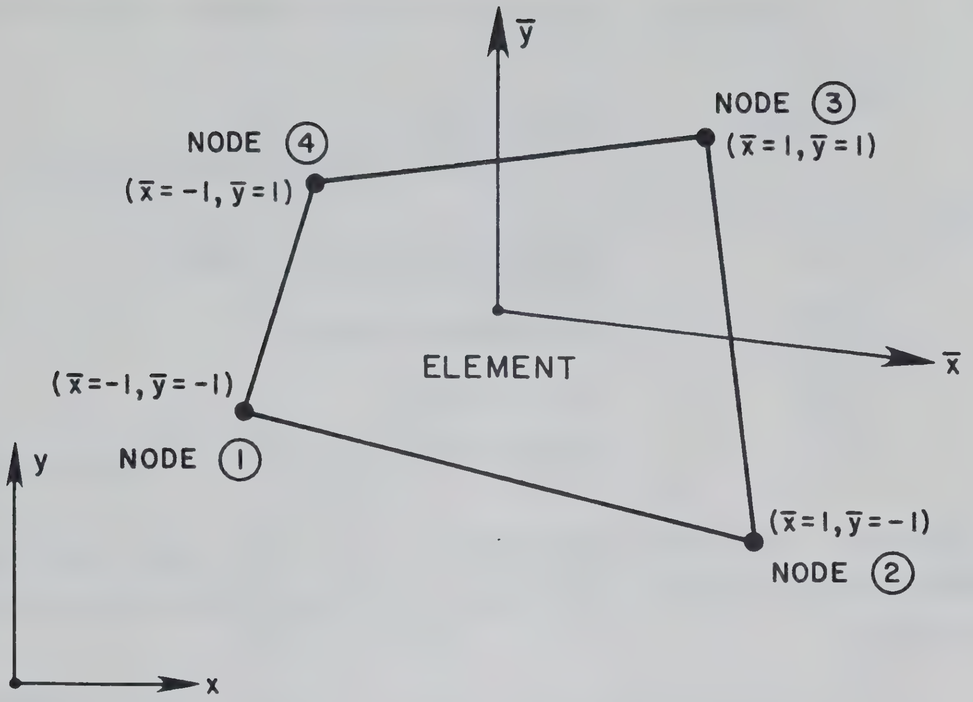
$\bar{y}$
NODE ③
$(\bar{x} = 1, \bar{y} = 1)$
NODE ④
$(\bar{x} = -1, \bar{y} = 1)$
ELEMENT
$\bar{x}$
$(\bar{x} = -1, \bar{y} = -1)$
NODE ①
y
$(\bar{x} = 1, \bar{y} = -1)$
NODE ②
x

FIGURE 2.2 TWO-DIMENSIONAL ISOPARAMETRIC ELEMENT

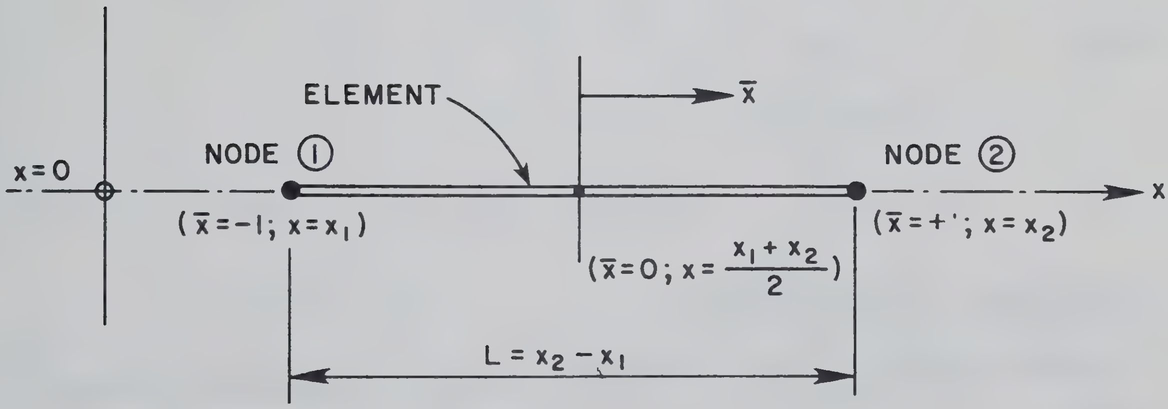
ELEMENT
$\bar{x}$
x = 0
NODE ①
NODE ②
x
$(\bar{x} = -1;\ x = x_1)$
$(\bar{x} = +';\ x = x_2)$
$(\bar{x} = 0;\ x = \frac{x_1 + x_2}{2})$
$L = x_2 - x_1$

FIGURE 2.3 ONE-DIMENSIONAL ISOPARAMETRIC ELEMENT

where

$$H_i(\bar{x}, \bar{y}) = \frac{1}{4}(1 + \bar{x}\,\bar{x}_i)(1 + \bar{y}\,\bar{y}_i) \tag{2.25}$$

(linear interpolation function)

$\bar{x}_i, \bar{y}_i$ - natural coordinates of node i (either 1 or -1)

$T_i(t)$ - temperature of node i

$< H_i >$ - $< H_1\ H_2\ H_3\ H_4 >$

$\{ T_i \}$ - column vector of nodal point temperatures

Similarly, the global coordinates of any point within the element are related to the global coordinates of the nodal points by the following equation:

$$\underset{2\times1}{\begin{Bmatrix} x \\ y \end{Bmatrix}} = \underset{2 \times 8}{\begin{bmatrix} < H_i > & 0 \\ 0 & < H_i > \end{bmatrix}} \underset{8 \times 1}{\begin{Bmatrix} \{x_i\} \\ \{y_i\} \end{Bmatrix}} \tag{2.26}$$

where

$$\{x_i\}^T = < x_1\ x_2\ x_3\ x_4 >$$

$$\{y_i\}^T = < y_1\ y_2\ y_3\ y_4 >$$

are the nodal point coordinates.

Differentiation of Eq. (2.24) with respect to spatial coordinates yields:

$$\underset{2 \times 1}{\begin{Bmatrix} \dfrac{\partial T}{\partial x} \\[2ex] \dfrac{\partial T}{\partial y} \end{Bmatrix}} = \underset{2 \times 4}{\begin{bmatrix} < \dfrac{\partial H_i}{\partial x} > \\[2ex] < \dfrac{\partial H_i}{\partial y} > \end{bmatrix}} \underset{4 \times 1}{\{T_i\}} = [B]\,\{T_i\} \tag{2.27}$$

The relationship between spatial and natural derivatives is

$$\underset{2 \times 1}{\begin{Bmatrix} \dfrac{\partial}{\partial \bar{x}} \\ \dfrac{\partial}{\partial \bar{y}} \end{Bmatrix}} = \underset{2 \times 2}{[J]} \; \underset{2 \times 1}{\begin{Bmatrix} \dfrac{\partial}{\partial x} \\ \dfrac{\partial}{\partial y} \end{Bmatrix}} \tag{2.28}$$

where

$$[J] = \begin{bmatrix} \dfrac{\partial x}{\partial \bar{x}} & \dfrac{\partial y}{\partial \bar{x}} \\ \dfrac{\partial x}{\partial \bar{y}} & \dfrac{\partial y}{\partial \bar{y}} \end{bmatrix} \tag{2.29}$$

is the Jacobian matrix. From Eq. (2.26) it can be shown that

$$\underset{2 \times 2}{[J]} = \underset{2 \times 4}{\begin{bmatrix} \dfrac{\partial H_1}{\partial \bar{x}} & \dfrac{\partial H_2}{\partial \bar{x}} & \dfrac{\partial H_3}{\partial \bar{x}} & \dfrac{\partial H_4}{\partial \bar{x}} \\ \dfrac{\partial H_1}{\partial \bar{y}} & \dfrac{\partial H_2}{\partial \bar{y}} & \dfrac{\partial H_3}{\partial \bar{y}} & \dfrac{\partial H_4}{\partial \bar{y}} \end{bmatrix}} \underset{4 \times 2}{\begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y_4 \end{bmatrix}} \tag{2.30}$$

Use of Eq. (2.28) in Eq. (2.27) yields

$$\underset{2 \times 4}{[B]} = \underset{2 \times 4}{\begin{bmatrix} < \dfrac{\partial H_i}{\partial x} > \\ < \dfrac{\partial H_i}{\partial y} > \end{bmatrix}} = \underset{2 \times 2}{[J]^{-1}} \; \underset{2 \times 4}{\begin{bmatrix} < \dfrac{\partial H_i}{\partial \bar{x}} > \\ < \dfrac{\partial H_i}{\partial \bar{y}} > \end{bmatrix}} \tag{2.31}$$

The element conductivity matrix is given by

$$\underset{4\times4}{\underline{K_m}} = \int_{Vol.} k_m \; \underset{4\times2}{\underline{B}^T} \; \underset{2\times4}{\underline{B}} \; dv \tag{2.32}$$

or integrating in the natural coordinate system

$$\underset{4\times4}{\underline{K_m}} = t \int_{-1}^{+1} \int_{-1}^{+1} k_m \; \underset{4\times2}{\underline{B}^T} \; \underset{2\times4}{\underline{B}} \; |J| \; d\bar{x} \; d\bar{y} \tag{2.33}$$

where

t - - thickness of element
$|J|$ - - determinant of Jacobian

If k_m is constant throughout the element, the above integral reduces to

$$\underset{4\times4}{\underline{K_m}} = k_m \; t \int_{-1}^{+1} \int_{-1}^{+1} \underset{4\times4}{\underline{f}} \, (\bar{x}, \bar{y}) \, d\bar{x} \, d\bar{y} \tag{2.34}$$

where

$$\underset{4\times4}{\underline{f}} \, (\bar{x}, \bar{y}) = \underset{4\times2}{\underline{B}^T} \; \underset{2\times4}{\underline{B}} \; |J| \tag{2.35}$$

Numerical integration of Eq. (2.34) by 2-point Gauss quadrature gives the following equation:

$$\int_{-1}^{+1} \int_{-1}^{+1} \underset{4\times4}{\underline{f} \, (\bar{x}, \bar{y}) \, d\bar{x} \, d\bar{y}} = \sum_{i=1}^{2} \sum_{j=1}^{2} \underset{4\times4}{\underline{f} \, (\bar{x}_i, \bar{y}_j)} \tag{2.36}$$

where

$\bar{x}_i, \bar{y}_j$ - coordinates of integration points either $+\sqrt{3}/3$ or $-\sqrt{3}/3$

The computational scheme is as follows. First, spatial derivatives of $< H_i >$ are evaluated at integration point $(\bar{x}_i, \bar{y}_i)$. Then these derivatives are used in Eq. (2.30), along with the known global coordinates, (x_1, x_2, x_3, x_4) and (y_1, y_2, y_3, y_4), of the element corners, to obtain the Jacobian matrix $\underline{J}(\bar{x}_i, \bar{y}_i)$ at the integration point $(\bar{x}_i, \bar{y}_i)$. This matrix is inverted and used in Eq. (2.31) along with the spatial derivatives of $< H_i >$ at point $(\bar{x}_i, \bar{y}_i)$, to obtain the matrix $\underline{B}(\bar{x}_i, \bar{y}_i)$. Finally, the determinant of the Jacobian $|\underline{J}(\bar{x}_i, \bar{y}_i)|$ is calculated and used together with $\underline{B}(\bar{x}_i, \bar{y}_i)$ in Eq. (2.35) to obtain

$$\underset{4x4}{\underline{f}(\bar{x}_i, \bar{y}_i)} = \underset{4x2}{\underline{B}^T(\bar{x}_i, \bar{y}_i)} \; \underset{2x4}{\underline{B}(\bar{x}_i, \bar{y}_i)} \; |J(\bar{x}_i, \bar{y}_i)| \tag{2.37}$$

Equation (2.37) is evaluated at the four integration points to determine the total value of the integral in Eq. (2.36). Substitution into Eq. (2.34) completes the formation of the two-dimensional element stiffness matrix.

2.3.3 One-Dimensional Isoparametric Element

A two node one-dimensional isoparametric element is shown in Fig. 2.3. The natural coordinates, $\bar{x}$, of the two nodes are ±1. The x-axis represents the global coordinate system for the element.

The temperature at any point within the element is expressed in the natural coordinate system $(\bar{x})$ in terms of the temperature at nodes 1 and 2 by the following equation:

$$T(\bar{x}, t) = \sum_{i=1}^{2} H_i(\bar{x}) \cdot T_i(t) \tag{2.38a}$$

or in matrix form

$$\underset{1x1}{T(\bar{x}, t)} = \underset{1x2}{< H_i >} \; \underset{2x1}{\{T_i\}} \tag{2.38b}$$

where

$$H_i(\bar{x}) = \frac{1}{2}(1 + \bar{x}\,\bar{x}_i) \tag{2.39}$$

(linear interpolation function)

$\bar{x}_i$ - natural coordinates of node i (either 1 or -1)

$T_i(t)$ - temperature of node i

$< H_i > = < H_1 \; H_2 >$

$\{T_i\}$ - column vector of nodal point temperatures

Similarly, the global coordinate of any point within the element is related to the global coordinates of the nodal points by the following equation:

$$\underset{1\times1}{x} = \underset{1\times2}{< H_i >} \; \underset{2\times1}{\{x_i\}} \tag{2.40}$$

where

$$\{x_i\}^T = < x_1 \; x_2 >$$

Differentiation of Eq. (2.38) with respect to x yields:

$$\frac{\partial T}{\partial x} = \underset{1\times2}{< \frac{\partial H_i}{\partial x} >} \; \underset{2\times1}{\{T_i\}} = \underset{1\times2}{[B]} \; \underset{2\times1}{\{T_i\}} \tag{2.41}$$

Similar to the three-dimensional case, one obtains:

$$\frac{\partial}{\partial \bar{x}} = \frac{\partial x}{\partial \bar{x}} \frac{\partial}{\partial x} = J \frac{\partial}{\partial x} \tag{2.42}$$

where

$$J = \frac{\partial x}{\partial \bar{x}} \tag{2.43}$$

is the Jacobian. From Eq. (2.40) it can easily be shown that:

$$\frac{\partial x}{\partial \bar{x}} = \frac{\partial H_1}{\partial \bar{x}} x_1 + \frac{\partial H_2}{\partial \bar{x}} x_2 = -\frac{1}{2} x_1 + \frac{1}{2} x_2 = \frac{L}{2} \qquad (2.44)$$

where L is the length of the element.

Use of Eq. (2.42) in Eq. (2.41) yields:

$$[B] = < \frac{\partial H_i}{\partial x} > = J^{-1} < \frac{\partial H_i}{\partial \bar{x}} > = \frac{2}{L} < \frac{-1}{2} \; \frac{1}{2} > = < \frac{-1}{L} \; \frac{1}{L} > \qquad (2.45)$$

Finally, the element conductivity matrix is given by:

$$\underset{2x2}{\underline{K_m}} = \int_{Vol.} \underset{2x1}{\underline{B^T}} \; \underset{1x1}{\underline{k_m}} \; \underset{1x2}{\underline{B}} \; dv = \int_{Vol.} k_m \begin{Bmatrix} \frac{-1}{L} \\ \\ \frac{1}{L} \end{Bmatrix} < \frac{-1}{L} \; \frac{1}{L} > dv \qquad (2.46)$$

Since in this case all the terms under the integration sign are constant, there is no need for numerical integration and the integral can be evaluated explicitly as follows:

$$\begin{aligned} \underline{K_m} &= k_m \begin{Bmatrix} \frac{-1}{L} \\ \\ \frac{1}{L} \end{Bmatrix} < \frac{-1}{L} \; \frac{1}{L} > \int_{Vol.} dv \\ &= k_m \begin{Bmatrix} \frac{-1}{L} \\ \\ \frac{1}{L} \end{Bmatrix} < \frac{-1}{L} \; \frac{1}{L} > \cdot A \cdot L \qquad (2.47) \\ &= \frac{k_m \cdot A}{L} \begin{bmatrix} 1 & -1 \\ \\ -1 & 1 \end{bmatrix} \end{aligned}$$

where A is the area of the cross-section of the element.

2.4 Capacity Matrix [C]

The heat capacity associated with a node is the rate at which heat is absorbed for a unit rate of change of the temperature of that node. The capacity matrix is idealized through a system analogous to the lumping of mass in dynamic analysis. This approach has the important advantage of resulting in a diagonal capacity matrix. This lumping is achieved by delineating the volume adjacent to a node by a perimeter drawn through the centroids of the surrounding elements. Thus, the volume tributary to a node is found by adding a contribution from each element bounding the node, calculated as follows:

A. Three-Dimensional Isoparametric Element

The contribution of an element, m, to a node, i, is given as :

$$C_{m,i} = \frac{1}{8} V_m \; \rho(T) \; C_p(T) \tag{2.48}$$

where V_m is the volume of element adjacent to node i.

B. Two-Dimensional Isoparametric Element

The contribution of an element, m, to a node, i, is given as:

$$C_{m,i} = \frac{1}{4} V_m \; \rho(T) \; C_p(T) \tag{2.49}$$

where $V_m = t \cdot A$ is the volume of element adjacent to node i. A is the area and t is the thickness of the quadrilateral element.

C. One-Dimensional Isoparametric Element

The contribution of an element, m, to a node, i, is given as:

$$C_{m,i} = \frac{1}{2} V_m \; \rho(T) \; C_p(T) \tag{2.50}$$

where $V_m = A \cdot L$ is the volume of element adjacent to node i.

Therefore, the heat capacity of node i is

$$C_i = \sum_{m=1}^{M} C_{m,i} \qquad (2.51)$$

where

M - all elements adjacent to node i

Finally, the diagonal system capacity matrix $\underline{C}$ is assembled by repeating the above calculation for each node.

2.5 External Heat Flow Vector {Q}

The external heat flow vector term in the matrix equations (2.6) can be separated into its constituent parts as follows:

$$Q = Q_F + Q_p + Q_E \qquad (2.52)$$

where

Q_F - heat flow caused by the exposure of the system to an external source (e.g., a fire) on the boundary

Q_p - a prescribed heat flow on the boundary

Q_E - heat flow from an exothermic reaction within the system (e.g., concrete hydration, wood combustion)

Each of these three terms is calculated individually in FIRES-T3 as follows:

A. Convection and Radiation Boundary Conditions

The term Q_F is considered a function of both convective and radiative mechanisms. Fires normally affecting structures are here considered to be those in a post-flashover phase, which leads to the assumption of a uniform room temperature. The time-temperature relationship for a fire is represented by the function $T_f(t)$. It must realized that this temperature is at best a pseudo-representation of a very complex phenomenon.

The boundary of the system exposed to fire is assumed to be composed of surfaces bounding adjacent nodes. Thus, the external heat flow for a node can be represented by:

$$Q_F = A_F \cdot q(T_s, T_f) \tag{2.53}$$

where

A_F - tributary area for the node

q - rate of heat flow per unit area

T_s - surface temperature

T_f - temperature of pseudo-fire

The value of Q_F for a surface node exposed to fire is assembled by considering the contributions of surrounding surfaces.

The rate of heat flow can be modeled linearly or nonlinearly:

1. Linear heat transfer for fire:

$$q = h(T')(T_f - T_s) \tag{2.54}$$

where

$h(T')$ - heat transfer coefficient

$T' = (T_f + T_s)/2$

2. Nonlinear heat transfer from fire:

$$q = A(T_f - T_s)^N + V \cdot \sigma[a\varepsilon_f\theta_f^4 - \varepsilon_s\theta_s^4] \tag{2.55}$$

where

A - convection coefficient

N - convection power factor

V - radiation view factor

σ - Stefan-Boltzmann constant

a - absorption of surface

ε_f - emissivity of the flame associated with fire

θ_f - absolute temperature of fire

ε_s - surface emissivity

θ_s - absolute temperature of surface

B. Prescribed Heat Flow Boundary Condition

In this case, the prescibed heat flow at the nodes at different times, Q_p, are input directly to the computer program FIRES-T3.

C. Internal Heat Generation due to Exothermic Reaction

The heat flow at each node due to internal heat generation, Q_E, is assembled by considering the contribution of each element bounding the node, i.e.,

$$Q_{E,i} = \sum_{m=1}^{M} q_m(V, t)\, V_{m,i} \tag{2.56}$$

where

$Q_{E,i}$ = internal heat flow at node i

M = all elements adjacent to node i which generate heat

$q_m(V, t)$ = heat generation per unit volume in element m (time-dependent)

$V_{m,i}$ = portion of volume of element m that is tributary to node i

= $\frac{1}{8} V_m$ for three-dimensional elements

= $\frac{1}{4} V_m$ for two-dimensional elements

= $\frac{1}{2} V_m$ for one-dimensional elements

In FIRES-T3, the heat rate function $q_m(V, t)$ is input directly. Cooling is indicated by a negative sign.

2.6 Time Integration of Matrix Equations

The unknown nodal temperature vector, $\{T\}$, in the matrix equation (2.6) is a function of time, $\{T(t)\}$. Hence, this equation is actually a first order differential equation in n dimensions and must be further discretized by step-by-step integration. The continuous nodal temperature history $\{T(t)\}$ is represented by a finite sequence of temperature distributions $\{T(t_0)\}$, $\{T(t_1)\}$, $\{T(t_2)\}$, . . . By assuming that the variation of the temperature with time is linear within each time step (Fig. 2.4), the temperature rate of change $\{\dot{T}\}$ at any time t_i can be approximated in terms of nodal temperatures:

$$\{\dot{T}(t_i)\} = \{T(t_i) - T(t_{i-1})\}/\Delta t_i \tag{2.57}$$

where Δt_i is the time step between t_{i-1} and t_i. The differential equations (2.6) can now be reduced to a set of linear algebraic equations in the independent variable $\{T(t_i)\}$. There will be a set of equations for each time t_i, $i = 1, 2, . . .$, and the step-by-step solution of each set results in an approximation to the nodal temperature history $\{T(t)\}$ and, using Equations (2.8), (2.24) or (2.38), an approximation to the overall temperature distribution history $T(x, y, x, t)$, $T(x, y, t)$ or $T(x, t)$. The accuracy of this finite element step-by-step integration approximation increases with the number of elements and with the smallness of time steps.

To facilitate discussion of the solution scheme and the incorporation of boundary conditions into the equations, let Eq. (2.6) be partitioned in the following form:

$$\left[\begin{array}{c|c} C_{aa} & 0 \\ \hline 0 & C_{bb} \end{array}\right] \left\{\begin{array}{c} \dot{T}_a(t_i) \\ \hline \dot{T}_b(t_i) \end{array}\right\} + \left[\begin{array}{c|c} K_{aa} & K_{bb} \\ \hline K_{ba} & K_{bb} \end{array}\right] \left\{\begin{array}{c} T_a(t_i) \\ \hline T_b(t_i) \end{array}\right\} = \left\{\begin{array}{c} Q_a(t_i) \\ \hline Q_b(t_i) \end{array}\right\} \tag{2.58}$$

where

T_a - unknown nodal temperatures

T_b - known (prescribed) nodal temperatures

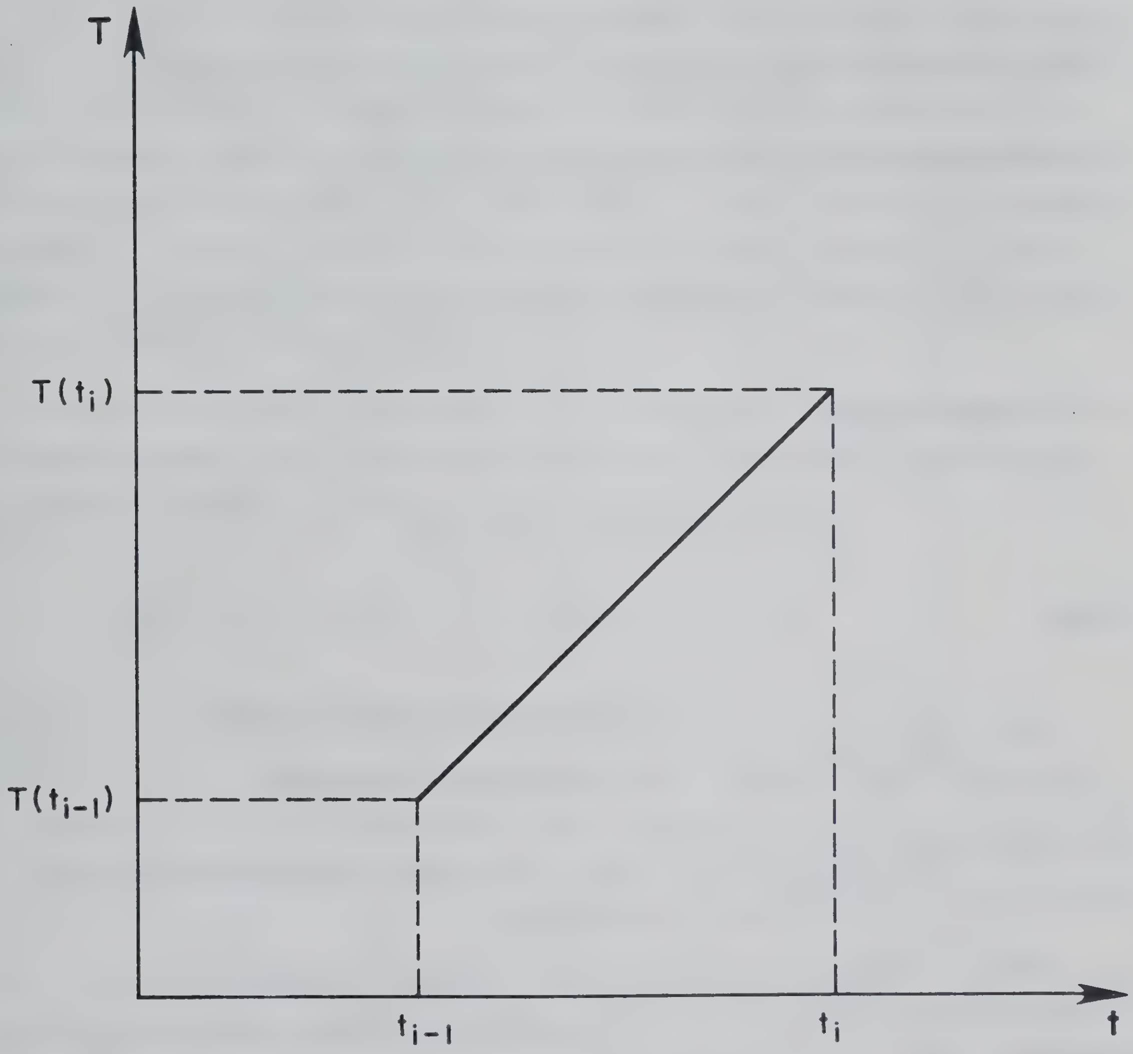

FIGURE 2.4 VARIATION OF TEMPERATURE WITH TIME WITHIN A TIME INCREMENT

Q_a - known external nodal heat flow

Q_b - unknown nodal heat flow

Static condensation can be used to remove known temperature nodes from the equations, resulting in:

$$[C_{aa}]\{\dot{T}_a(t_i)\} + [K_{aa}]\{T_a(t_i)\} = \{Q_a(t_i)\} - [K_{ab}]\{T_b(t_i)\} \qquad (2.59)$$

Substitution of Eq. (2.57) into Eq. (2.59) yields:

$$[K_{aa} + \frac{C_{aa}}{\Delta t_i}]\{T_a(t_i)\} = \{Q_a(t_i) - [K_{ab}]\{T_b(t_i)\} + \frac{C_{aa}}{\Delta t_i}\{T_a(t_{i-1})\}\} \qquad (2.60a)$$

or in compact form

$$[K]^*\{T_a(t_i)\} = \{Q(t_i)\}^* \qquad (2.60b)$$

where

$[K]^*$ - effective conductivity matrix

$\{Q(t_i)\}^*$ - effective heat flow vector

The nodal temperatures at t_i, $T(t_i)$, are found directly by solving the above set of linear algebraic equations.

Both $\underline{K}^*$ and $\underline{Q}^*$ can be functions of the current temperature $\underline{T}(t_i)$, since material properties and fire boundary conditions can be temperature-dependent. There are two basic approaches that can be used to resolve this problem.

1. Use the temperature distribution from the previous time step, $\underline{T}(t_{i-1})$, to calculate the necessary values and thus solve Eq. (2.60) directly, or
2. Use an iterative solution technique that allows the necessary variables to be continually revised on the basis of the current solution.

The type of numerical solution technique often used in solving linear algebraic equations - i.e. triangularization of $\underline{K}^*$ and then the back substitution of $\underline{Q}^*$ in order to obtain $\underline{T}(t_i)$ - offers an additional variation on the previously mentioned options. It is possible to derive $\underline{K}^*$ on the basis of the previous temperature distribution, triangularize $\underline{K}^*$, and then, with the use of an iterative technique, achieve a more accurate temperature vector in the determination of $\underline{Q}^*$. This separation into triangularization and back substitution is ideal for use in simulating fire phenomena since $\underline{Q}^*$ is extremely sensitive to the surface temperature of the structure. The effective conductivity matrix $\underline{K}^*$ tends to be far less sensitive to temperature than $\underline{Q}^*$. FIRES-T3 contains the option of either solving the entire problem ($\underline{K}^*$ and $\underline{Q}^*$) iteratively, or considering only the fire boundary condition term ($\underline{Q}^*$) in the iteration.

To help accelerate convergence in the iterative processes, an over-convergence factor, β, is used in estimating the temperature distribution of the next iteration, j + 1.

$$\underline{T}^{j+1}(t_i) = \underline{T}^{j}(t_i) + \beta\,(\underline{T}^{j}(t_i) - \underline{T}^{j-1}(t_i)) \tag{2.61}$$

Experience has shown that β should vary from -0.10 to -0.40 in the case of the nonlinear fire condition. Convergence is achieved when the temperature distribution of two successive iterations coincide within a prescribed level of error expressed as

$$\frac{2 \cdot \left| T^{j}(t_i) - T^{j-1}(t_i) \right|}{\left| T^{j}(t_i) + T^{j-1}(t_i) \right|} < \text{permissible error} \tag{2.62}$$

The step-by-step assembly and solution of Eq. (2.60) gradually traces out the temperature history in the structure.

The structure of FIRES-T3 is shown in the following flow charts. Fig. 2.5 shows the organization of the main subroutine (FIRES-T3) which inputs the data describing the problem. The subroutine which controls step-by-step integration (HEATFLO) is presented in Fig. 2.6.

An important feature of FIRES-T3 is that all system variables are

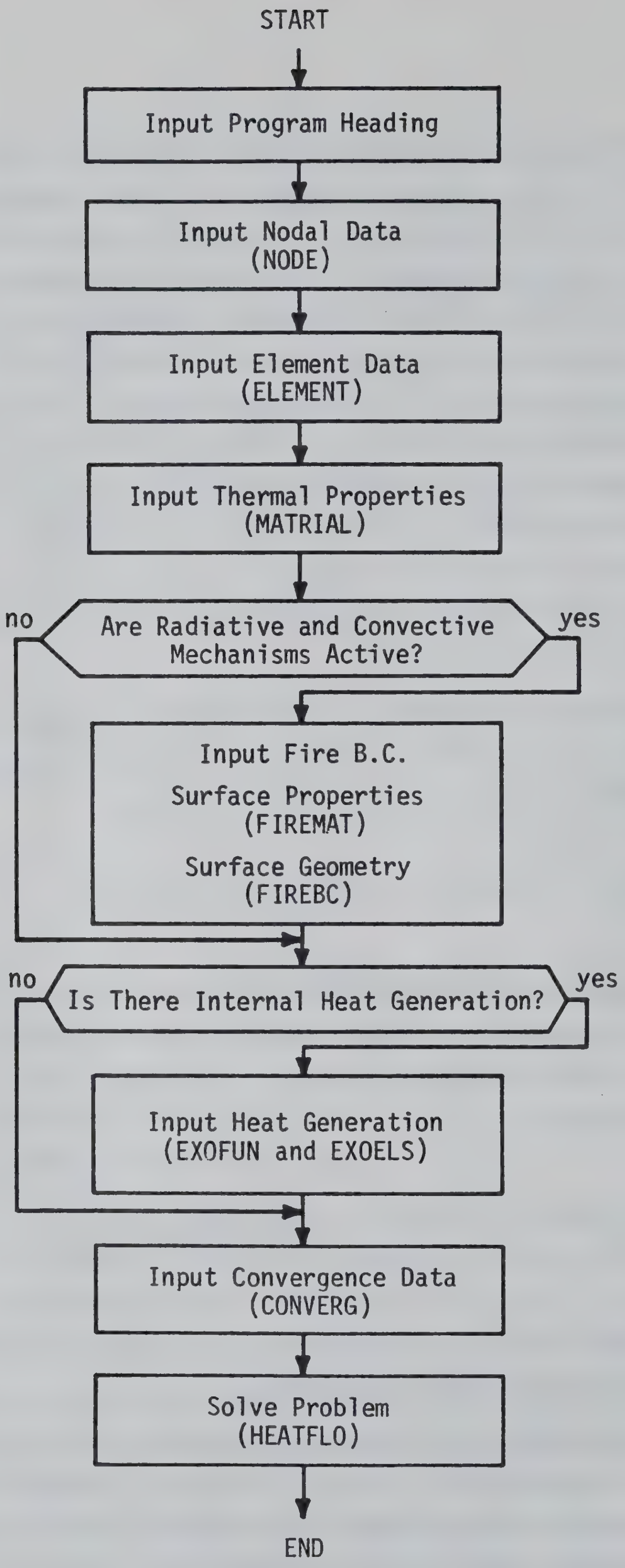

FIGURE 2.5 FLOW CHART FOR PROGRAM FIRES-T3

(Titles in Parenthesis are Names of Subroutines)

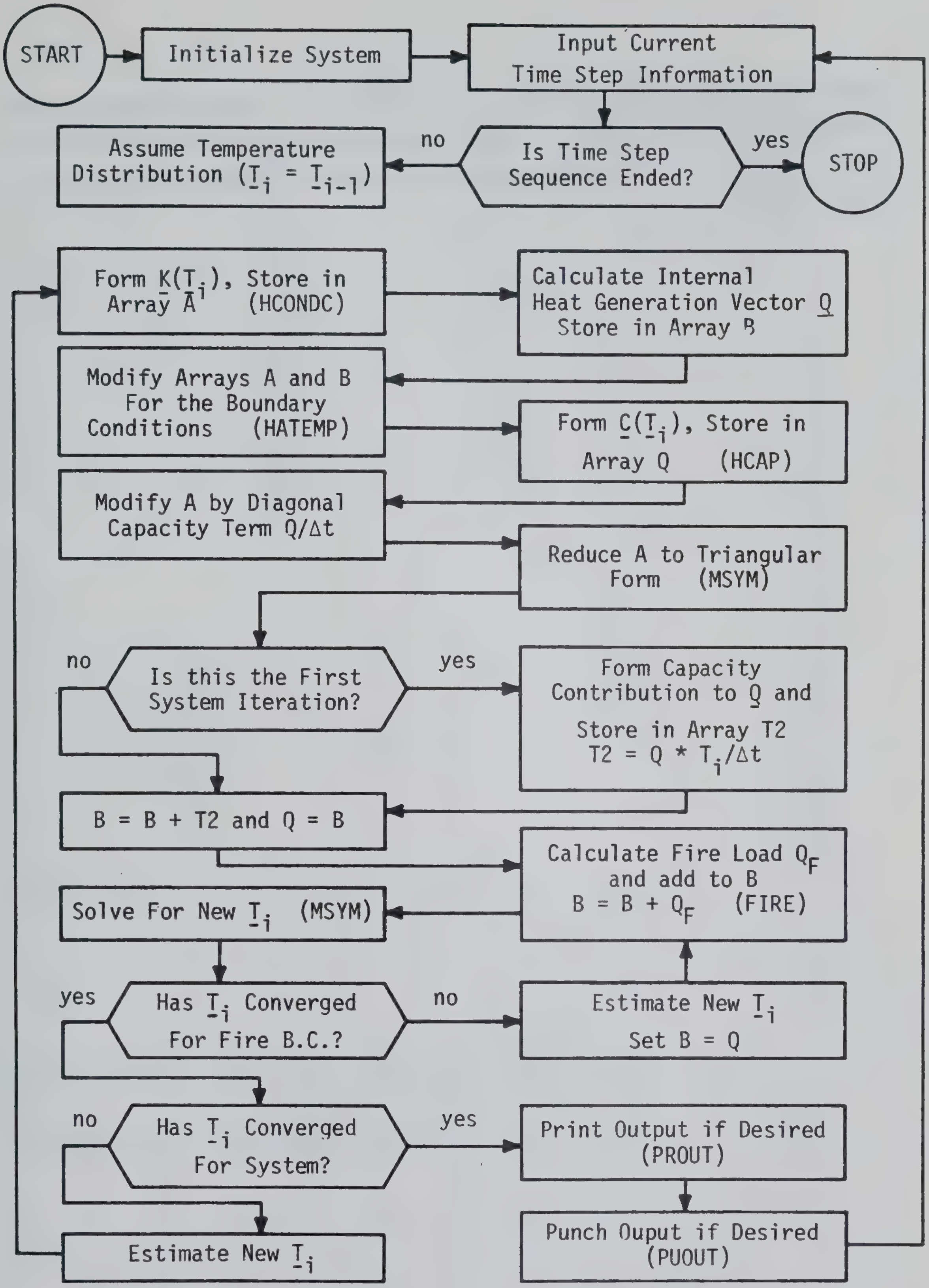
START
Initialize System
Input Current Time Step Information
Is Time Step Sequence Ended?
yes
STOP
no
Assume Temperature Distribution ($\underline{T}_i = \underline{T}_{i-1}$)
Form $K(\underline{T}_i)$, Store in Array $\bar{A}^1$ (HCONDC)
Calculate Internal Heat Generation Vector $\underline{Q}$ Store in Array B
Modify Arrays A and B For the Boundary Conditions (HATEMP)
Form $\underline{C}(\underline{T}_i)$, Store in Array Q (HCAP)
Modify A by Diagonal Capacity Term Q/Δt
Reduce A to Triangular Form (MSYM)
Is this the First System Iteration?
no
yes
Form Capacity Contribution to $\underline{Q}$ and Store in Array T2 $T2 = Q * T_i/\Delta t$
B = B + T2 and Q = B
Calculate Fire Load Q_F and add to B $B = B + Q_F$ (FIRE)
Solve For New $\underline{T}_i$ (MSYM)
Has $\underline{T}_i$ Converged For Fire B.C.?
yes
no
Estimate New $\underline{T}_i$ Set B = Q
Has $\underline{T}_i$ Converged For System?
no
yes
Print Output if Desired (PROUT)
Punch Ouput if Desired (PUOUT)
Estimate New $\underline{T}_i$

FIGURE 2.6 FLOW CHART FOR SUBROUTINE HEATFLO ASSUMING FIRE BOUNDARY CONDITIONS

(Titles in Parenthesis are Names of Program Subroutines) dynamically dimensioned. That is, the amount of computer storage space allotted for each variable is specified based on the size of the problem being analyzed. The organization of this dynamic dimensioning scheme is shown in Table 2.1.

ADDRESS	DIMENSION	ARRAY	CONTENTS
N1=1	NUMNP	X	X-coordinates of nodes
N2	NUMNP	Y	Y-coordinates of nodes
N3	NUMNP	Z	Z-coordinates of nodes
ND0	NUMNP	KODE	Indicator for type of boundary condition (Flow or Temperature)
ND1	NUMNP	ID or D	Intermediate storage needed in calculations
ND2	NUMNP	MA	
ND3	NUMNP	T1	
ND4	NUMNP	T2	
ND5	NUMNP	T3	

TABLE 2.1 DYNAMICALLY DIMENSIONED STORAGE ALLOCATION FOR FIRES-T3

ADDRESS	DIMENSION	ARRAY	CONTENTS
N4	2 * NEL1D + 4 * NEL2D + 8 * NEL3D	LM	Nodal points of elements
N5	NUMEL	MMTYPE	Material types of elements
N6	NEL1D	BAREA	Cross-sectional areas of one-dimensional elements
N7	NEL2D	THICK	Thickness of two-dimensional elements
NV	NEL3D	VOLUME	Volumes of three-dimensional elements
N8	6 * NMAT	MATL	Control data for material properties
N9	NSTORE	XYS	Storage for material properties
N10	NBCMAT	MAT	Control data for fire B.C. properties
N11	NSTORE	FXYS	Fire B. C. properties

TABLE 2.1 (cont.)

ADDRESS	DIMENSION	ARRAY	CONTENTS
N12	NUMFBC	LI	Nodes bounding surface segments for fire B.C.
N13	NFBC2D + NFBC3D	LJ	
N14	NFBC3D	LK	
N15	NFBC3D	LL	
N16	NUMFBC	LMAT	Fire boundary type
N17	NUMFBC	LFIRE	Fire number
N18	NUMFBC	AIJKL	Area of surface segment
N19	NFBC1D + NFBC2D	LELEM	Element bounding surface segment
N20	3 * NQINT	IEXO	Control data for internal heat generation curves

TABLE 2.1 (cont.)

ADDRESS	DIMENSION	ARRAY	CONTENTS
N21	NSTORE	EXYS	Internal heat generation curves
N22	NINT	IEL	Elements with internal heating
N23	NINT	IMAT	Heating curve for each element
N24	NINT	VEL	Volume of each element
N25	NUMNP	Q	Heat flow vector
N26	NUMNP	T	Temperature vector
N27	NUMNP	B	Loading vector used in analysis
N28	NUMEL	AT	Element temperatures
N29	NUMNP * NBAND	A	Effective conductivity matrix
NTOTAL			

TABLE 2.1 (cont.)

3. COMMENTARY

FIRES-T3 and its predecessor FIRES-T have been used to solve a wide variety of heat flow problems [4, 7]. Experience gained in these analyses is drawn upon to present here a brief commentary on practical aspects of using the program.

Few difficulties are encountered in thermal analyses governed by specified temperature or heat flow boundary conditions. The principal factors which determine the effective use of the program are the layout of the finite element mesh and the selection of time-step intervals. On the one hand both must be fine enough to properly model the thermal behavior of the structure, and on the other as few elements as possible should be used since computational effort increases roughly with the cube of the number of nodes. Also, nodes should be numbered in such a way as to minimize the bandwidth of the resulting matrix equations. Time-step size can vary during the time integration to most efficiently reflect the expected rate of temperature change.

The heat flow problem is nonlinear whenever conductivity or heat capacity are temperature-dependent. However, with models of thermal properties used here this nonlinearity is negligible within a time step and adequate results are obtained by a linearized analysis (number of iterations = 0), thereby greatly reducing solution cost. When boundary conditions are linear, convergence is effected in a few iterations with little likelihood of instability. However, the fire boundary condition, including both conduction and radiation terms, is highly nonlinear and in order to ensure convergence of an iterative solution the time step size must be kept quite small, since numeric instability in the region of the fire surface can result when fire temperatures are high. A higher-order nonlinear technique (such as Newton-Raphsen iteration) would improve stability and convergence rate of the solution and may be incorporated into a future version of FIRES-T3. Over-convergence factors also improve the stability of the nonlinear iteration and are recommended when using the nonlinear fire boundary condition. When divergence occurs at some time step in an analysis, it is best to shorten the time step size for the remaining part of the analysis and restart the step-by-step solution from the last converging time step. Therefore, whenever it is impossible to know a priori the time step sizes needed, nodal temperatures should be punched at each time step in case a restart is necessary.

The fire environment in FIRES-T3 is modeled through a pseudo-fire, defined by a time-temperature curve, and the convective and radiative heat flow terms in the fire boundary condition. The phenomena associated with heat transfer in the turbulent environment of a fire are difficult to model exactly. The possibility of including the temperature dependence of the related parameters may be included, and the detailed temperature and flow fields in a fire compartment may be modeled by subdividing the fire into zones with different characteristics. In the pseudo-fire concept the critical parameters appear to be the emissivity of both the flame and the surface of the structural element. This assumes that at the temperatures normally associated with fires, the radiative heat transfer mechanism predominates. At present, a value of 0.9 is used for the emissivity of concrete. The value of flame emissivity appears to be more uncertain with potential values ranging from 0.3 to 0.9. Current work indicates a possible dependency of the flame emissivity on the particular content of the flame, which may vary greatly from the controlled fire of a test furnace to that of the uncontrolled environment of an actual fire. In addition, radiation sources, compartment enclosure surfaces, may contribute to the overall fire boundary condition problem.

The radiation component of heat transfer at a boundary of an element exposed to fire depends on the spatial configuration of the enclosure, the geometry of the element under consideration, and the emissivities of the fire, the element surface, and the enclosure surface. For concrete structural elements surrounded by fire the effective emissivity ε falls in the range of 0.3 to 0.9 [9]. The radiation boundary condition in Equation (2.55) is an attempt to represent the influence of the fire and the element surface emissivities on the radiative heat transfer. This approximation is sensitive to the selection of ε_f and ε_s values. Unless it can be shown by comparison with experimental data that this approximation give reliable results, it is recommended that for concrete structures exposed to fire both values of ε_f and ε_s where $0.5 < \varepsilon < 0.7$ be replaced by effective emissivity ε.

The capability of modeling internal heat generation in FIRES-T3 introduces no numerical complications or sensitivities. This option could be used to include the effects of internal combustion in a fire analysis [5]. Also, it could solve a variety of other temperature problems such as determining temperature rise in mass concrete due to hydration of cement paste [4].

ACKNOWLEDGEMENTS

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The work presented in this report is an extension of earlier work by Zuhayr Nizamuddin [7], Jim Becker et al [1] and Hani Bizri [3].

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APPENDIX A

INPUT INSTRUCTIONS FOR FIRES-T3

APPENDIX A - INPUT INSTRUCTIONS FOR FIRES-T3

Contents

I. Heading Card A-4

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V. Fire Boundary Condition Data A-13

VI. Internal Heat Generation Data A-19

VII. Convergence Criteria A-22

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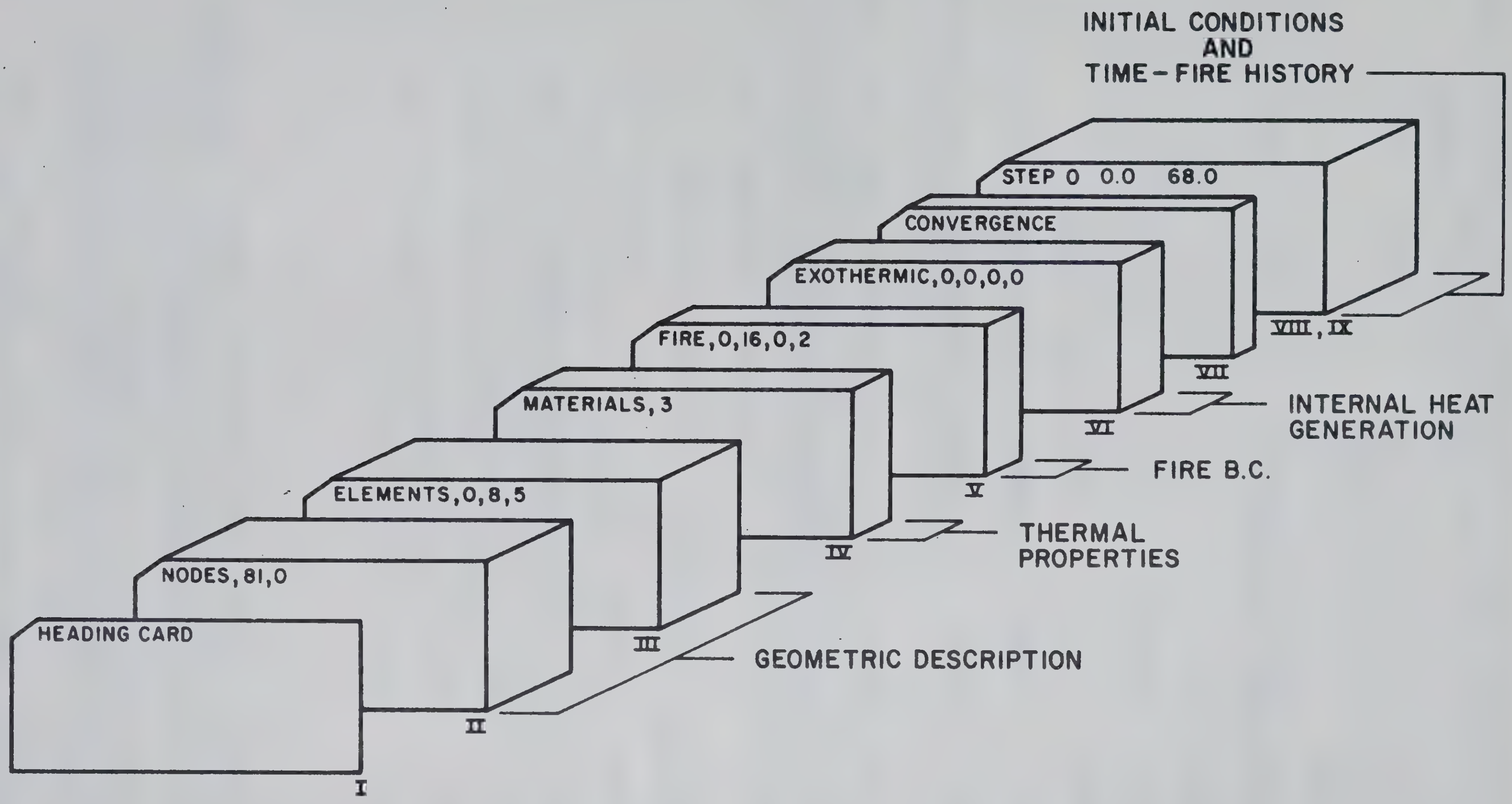


FIGURE A.1 TYPICAL INPUT DECK FOR FIRES-T3

I. HEADING CARD (6A10)

NOTE/ Begin each new data case with a heading card. To halt the program insert two blank cards instead of a heading card.

II. NODAL DATA

A. Control Card (Alphanumeric)

NODES, N1, N2

note	field	variable	entry
(1)	NODES	--	Enter the word "NODES"
	N1	NUMNP	Number of nodal points
	N2	NTBC	Number of nodal points with a specified temperature boundary condition

NOTE/ This is an alphanumeric control card containing both a key word (NODES) to identify the block of input data to follow and control parameters (N1 and N2) for that block of data. Alphanumeric control cards are left-justified with no blanks in the list. Note the examples in Fig. A.1.

B. Nodal Cards (I5,3E10.0)

note	columns	variable	entry
(1)	1-5	N	Nodal point number
(2)	6-15	X(N)	X-coordinate
	16-25	Y(N)	Y-coordinate
(3)	26-35	Z(N)	Z-coordinate

NOTES/

(1) Nodal point cards must be in numerical sequence. If cards are omitted, the missing nodes are generated at equal intervals along a straight line between the bounding nodal points.

(2) Nodal coordinates may be input using any system of units. However, this same system must be used to define all other input quantities that follow.

(3) In purely two-dimensional heat flow problems, leave the Z-coordinate blank.

C. Specified Temperature Nodes (16I5)

Omit this card if (N2) on the control card is zero

note	columns	variable	entry
(1)	1-5	ID(1)	Node number of first node in which temperature is fixed as a boundary condition
	6-10	ID(2)	Node number of second specified temperature node
	.	.	.
	.	.	.
	.	.	.
	.	.	.
(2)	.	ID(N2)	Continue until all N2 nodes are input

NOTES/

(1) Three types of boundary conditions are possible in FIRES-T3:

1) Temperature specified

2) Heat flow specified

3) Fire B.C.

If the first type of B.C. is to be used, all nodes with a specified temperature must be identified on this card. Actual temperatures are input later in Data Block IX. All boundary nodes not specified here are assumed to have a boundary condition of type 2 or type 3.

(2) Input 16 temperature nodes per card.

III. ELEMENT DATA

A. Control Card (Alphanumeric)

ELEMENTS, N1, N2, N3

note	field	variable	entry
(1)	ELEMENTS	--	Enter the word "ELEMENTS"

(2)	N1	NELID	Number of one-dimensional elements
(3)	N2	NEL2D	Number of two-dimensional elements
(4)	N3	NEL3D	Number of three-dimensional elements

NOTES/

(1) This is an alphanumeric control card with key word (ELEMENTS) and control parameters (N1, N2 and N3) as in Fig. A.1.

(2) Enter the total number of one-dimensional elements to be used. If 1-D elements are not to be used, enter "0" as N1.

(3) Enter the number of two-dimensional elements. If 2-D elements are not used, enter "0" as N2.

(4) Enter the number of three-dimensional elements. If 3-D elements are not used, enter "0" as N3.

A single mesh may utilize all three of the above element types.

B. One-Dimensional Element Cards (4I5, F10.0)

Omit these cards if (N1) on the control card above is zero

note	columns	variable	entry
(1)	1-5	NUM	Element number GE.1 and LE. NEL1D
(2)	6-10	I	Nodal point I
	11-15	J	Nodal point J
(3)	16-20	MTYPE	Material identification number
(4)	21-30	BAREA	Cross-sectional area of one-dimensional element

NOTES/

(1) Elements must be input in ascending element number order. If element cards are missing, the program generates the missing elements by incrementing NUM and nodal points I and J. A generated element assumes the material type and cross-sectional area of the element immediately preceding it. The last one-dimensional element in the mesh cannot be generated.

(2) The program uses isoparametric bar elements defined by their end nodes I and J, as shown in Fig. A.2(a). Enter the global node number of each end node. These one-dimensional bar elements may be used in a two- or three-dimensional nodal mesh. Any orientation in space is permissible.

(3) One or more sets of thermal material properties are input in the next data block, each of them labelled by an identification number. Enter the identification number of the material this element is composed of.

(4) Enter the cross-sectional area of the one-dimensional element, as shown in Fig. A.2. For a purely one-dimensional analysis, set (BAREA) equal to unity (1.0).

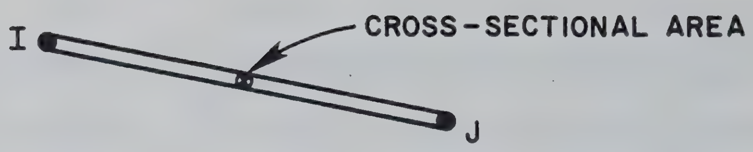
C. Two-Dimensional Element Cards (6I5, F10.0)

Omit these cards if (N2) on the control card above is zero.

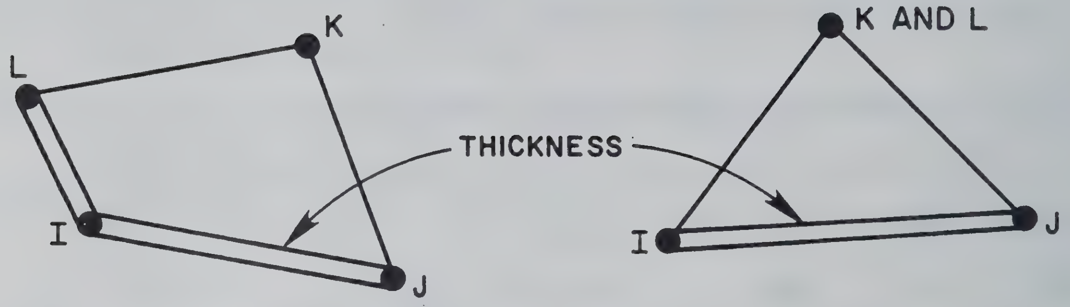
note	columns	variable	entry
(1)	1-5	NUM	Element number GE.1 and LE. NEL2D
(2)	6-10	I	Nodal point I
	11-15	J	Nodal point J
	16-20	K	Nodal point K
	21-25	L	Nodal point L
(3)	26-30	MTYPE	Material identification number
(4)	31-40	THICK	Thickness of two-dimensional element EQ.0.0, default of 1.0 used

NOTES/

(1) Two-dimensional elements must be input in ascending element number order. Start with "1" even if one-dimensional elements have also been used. If element cards are missing, the program generates the missing elements by incrementing NUM and nodal points I, J, K, and L. A generated element assumes the material type and thickness of the element immediately preceding it. The last two-dimensional element in the mesh cannot be generated.



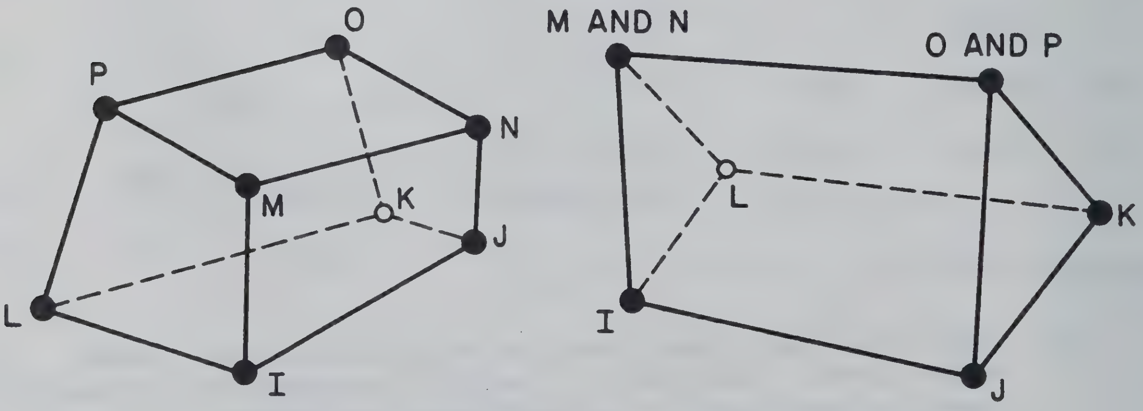
(a) ONE-DIMENSIONAL ELEMENT



QUADRILATERAL

DEGENERATE QUADRILATERAL
(TRIANGLE)

(b) TWO-DIMENSIONAL ELEMENTS



HEXAHEDRON

TYPICAL
DEGENERATE HEXAHEDRON

(c) THREE-DIMENSIONAL ELEMENTS

FIGURE A.2 ELEMENTS AVAILABLE IN FIRES-T3

(2) The program uses quadrilateral isoparametric elements defined by their corner nodes (I, J, K, L). Enter the global node number corresponding to each of these four corner nodes in counterclockwise order, as shown in Fig. A.2(b). Triangular elements can be formed by specifying a degenerate quadrilateral, i.e., by letting K and L be defined by the same global nodal point (see Fig. A.2(b)).

These two-dimensional elements may be used in three-dimensional analyses. It is most economical to define two-dimensional elements in an (X, Y) plane (Z = constant, not necessarily zero). However, it is also possible to define two-dimensional elements in an (X, Z) plane or in a (Y, Z) plane. Two-dimensional flow in skewed planes must be modelled by a layer of three-dimensional elements.

(3) One or more sets of thermal material properties are input in the next data block, each of them labelled by an identification number. Enter the identification number of the material this element is composed of.

(4) Enter the thickness of the two-dimensional quadrilateral (or triangle), as shown in Fig. A.2(b). For a purely two-dimensional analysis, set (THICK) equal to unity (1.0).

D. Three-Dimensional Element Cards (10I5)

Omit these cards if (N3) on the control card above is zero

note	columns	variable	entry
(1)	1-5	NUM	Element number GE.1 and LE. NEL3D
(2)	6-10	I	Nodal point I
	11-15	J	Nodal point J
	16-20	K	Nodal point K
	21-25	L	Nodal point L
	26-30	M	Nodal point M
	31-35	N	Nodal point N
	36-40	O	Nodal point O
	41-45	P	Nodal point P
(3)	46-50	MTYPE	Material identification number

NOTES/

(1) Three-dimensional elements must be input in ascending element number order. Start with "1" even if one-dimensional or two-dimensional elements have also been used. If element cards are missing, the program generates the missing elements by incrementing NUM and nodal points I, J, K, L, M, N, O, and P. A generated element assumes the material type of the element immediately preceding it. The last element in the mesh cannot be generated.

(2) The program uses hexahedral isoparametric elements defined by their corner nodes (I, J, K, L, M, N, O, P). Enter the global node number corresponding to each of these eight corner nodes in counterclockwise order, bottom layer first, as shown in Fig. A.2(c). Pentahedral or tetrahedral elements may be formed by specifying a degenerate hexahedron, i.e., by letting certain corner nodes be defined by the same global nodal point (see Fig. A.2(c)). Three-dimensional elements are comparatively expensive to form and lower order elements (one-dimensional or two-dimensional) of appropriate thickness should be used in those portions of a solid where heat flow is one- or two-dimensional.

(3) One or more set of thermal material properties are input in the next data block, each of them labelled by an identification number. Enter the identification number of the material this element is composed of.

IV. THERMAL MATERIAL PROPERTY DATA

A. Control Card (Alphanumeric)

MATERIALS, N1

note	field	variable	entry
(1)	MATERIALS	--	Enter the word "MATERIALS"
	N1	NMAT	Number of different material types

NOTE/ This is an alphanumeric control card with key word (MATERIALS) and main control parameter (N1), as in Fig. A.1.

B. Material Data

Input the following set of cards for each material type:

1. Control Card (3I5)

note	columns	variable	entry
(1)	1-5	MK	Number of points used to define heat conductivity function EQ.0, constant conductivity
(1)	6-10	MCP	Number of points used to define specific heat capacity function EQ.0, constant heat capacity
(1)	11-15	MD	Number of points used to define density function EQ.0, constant density

NOTE/

(1) Each material type is characterized by three material parameters: thermal conductivity, thermal heat capacity, and density. Each of these may be input as a constant or as a tabular function of temperature. At least two points are needed to define each function, and linear interpolation is used between points.

2. Heat Conductivity (8E10.0)

note	columns	variable	entry
(1)	1-10	X(1)	Temperature of point 1
	11-20	Y(1)	Value of conductivity function at point 1
	21-30	X(2)	Temperature of point 2
	.	.	.
	.	.	.
	.	.	.
	.		
	.	Y(MK)	Continue until all (MK) points are input.

NOTE/

(1) Input the table that defines the heat conductivity function. Each point is described by an ordered pair (X, Y), where X is temperature and Y is the value of heat conductivity at that temperature, as shown in Fig. A.3. Input 4 such pairs per card and use as many cards as necessary. The table for the function must be defined over the entire temperature range to be considered in the solution process - i.e. extrapolation below the lowest point or beyond the highest point is not permitted.

If conductivity was specified constant with temperature (MK.EQ.0) enter the constant value in columns 1-10.

Units for material properties must be consistent with units used for other input quantities (nodal coordinates, temperature, time step size, etc.).

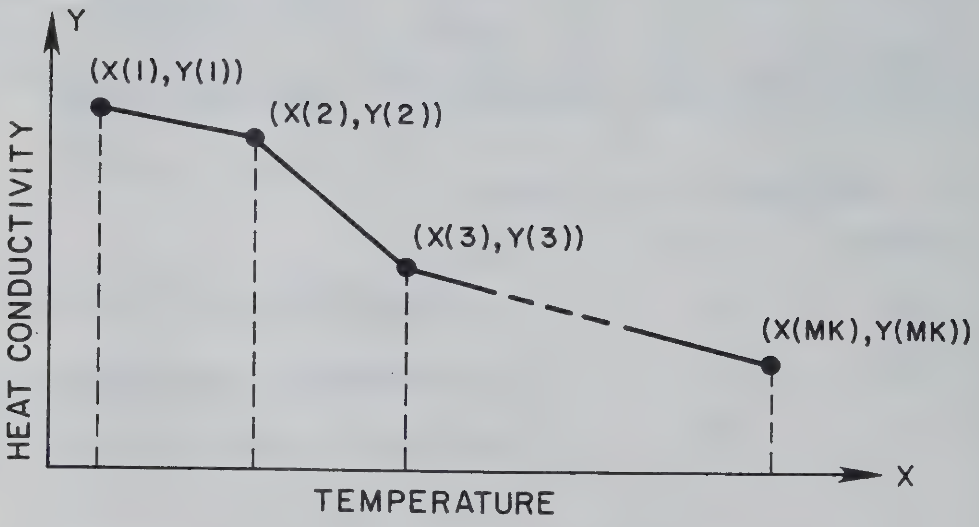


FIGURE A.3 MATERIAL PROPERTY TABLE FORMAT

3. Specific Heat Capacity (8E10.0)

(same as above)

4. Density (8E10.0)

(same as above)

V. FIRE BOUNDARY CONDITION DATA

A. Control Card (Alphanumeric)

FIRE, N1, N2, N3, N4

note	field	variable	entry
(1)	FIRE	-	Enter the word "FIRE"
(2)	N1	NFBC1D	Number of one-dimensional surface nodes exposed to fire
(2)	N2	NFBC2D	Number of two-dimensional surface segments exposed to fire
(2)	N3	NFBC3D	Number of three-dimensional surface areas exposed to fire
(3)	N4	NBCMAT	Number of different surface material types

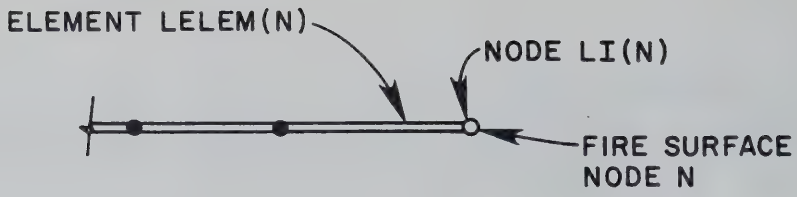
NOTES/

(1) This is an alphanumeric control card with key word (FIRE) and control parameters (N1, N2, N3, and N4), as shown in Fig. A.1.

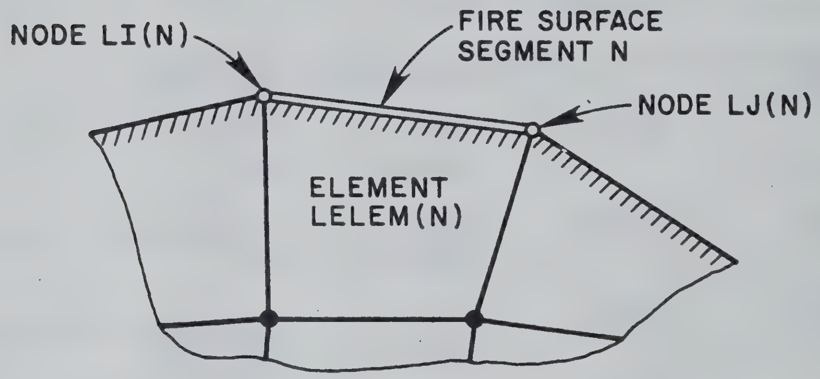
If fire boundary conditions are not to be used, insert as control card "FIRE, 0, 0, 0, 0" and go on to Data Block VI.

(2) The fire boundary condition is idealized through the identification of surface segments and their associated thermal properties. For one-dimensional elements, enter (N1), the total number of boundary nodes exposed to fire (see Fig. A.4(a)). For two-dimensional elements, enter (N2), the total number of element edges (surface segments) exposed to fire (see Fig. A.4(b)). For three-dimensional elements, enter (N3), the total number of element surfaces exposed to fire (see Fig. A.4(c)).

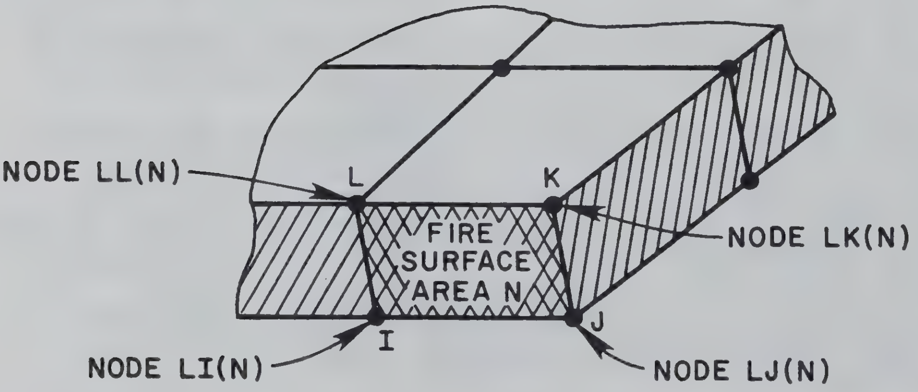
(3) Enter the number of different materials used to define fire surface properties.



(a) TYPICAL FIRE B.C. SURFACE NODE FOR 1-D ELEMENTS



(b) TYPICAL FIRE B.C. SURFACE SEGMENT FOR 2-D ELEMENTS



(c) TYPICAL FIRE B.C. SURFACE AREA FOR 3-D ELEMENTS

FIGURE A.4 DESCRIPTION OF FIRE SURFACE

B. Linear/Nonlinear Model Card (Alphanumeric)

note	columns	entry
(1)	1-9	Enter the word "LINEAR" or the word "NONLINEAR" - one or the other.

NOTE/

(1) Either a linear or a nonlinear model may be used for the fire boundary condition. Specify the type on this card.

C. Material Description

1. Linear Material Data

Omit if control card above is "NONLINEAR". Otherwise, input the following set of cards for each material type.

a. Control Card (I5)

note	columns	variable	entry
(1)	1-5	K	Number of points used to define linearized heat transfer function EQ. 0, constant function

NOTE/

(1) Linear surface material properties are input in the same way as conductivity, heat capacity and density in Data Block IV (page A-10)

b. Data Cards (8E10.0)

(same as previous material function input, IV.B.2 page A-11, 4 pairs per card

2. Nonlinear Material Data

Omit these cards if control card above is "LINEAR":

a. Constant Data Card (2E10.0)

note	columns	variable	entry
	1-10	SB	Stephan - Boltzman constant
	11-20	TSHIFT	Shift for absolute temperature

b. Material Data Card (6E10.0)

Input the following card for each material type:

note	columns	variable	entry
(1)	1-10	A	Convection factor
	11-20	P	Power of convection factor
	21-30	V	View factor for radiation term
	31-40	AB	Absorption of surface
	41-50	EF	Emmissivity of flame
	51-60	ES	Emmissivity of surface

NOTE/

See Page 22 for explanation of nonlinear fire boundary condition.

D. Description of Fire Surface

1. Control Card (Alphanumeric)

SURFACE, N1, N2, N3

note	field	variable	entry
(1)	SURFACE	--	Enter the word "SURFACE"
	N1	NS1	Number of one-dimensional surface nodes to be input below LE. NFBC1D
	N2	NS2	Number of two-dimensional surface segments to be input below LE. NFBC2D
	N3	NS3	Number of three-dimensional areas to be input below LE. NFBC3D

NOTE/

(1) This is an alphanumeric control card with key word (SURFACE) and control parameters (N1, N2, and N3), as shown in Fig. A.1. Enter the number of each type of fire B.C. surface elements that will be input on the cards that follow. The number of each type of element must be less than the maximums defined on Card V.A.

2. Description of One-Dimensional Fire Surface Nodes (16I5)

Omit this card if (N1) on control card above is zero:

note	columns	variable	entry
(1)	1-5	LI(1)	Node number of first boundary surface node
(2)	6-10	LMAT(1)	Material type for this surface node LE. NBCMAT
(3)	11-15	LFIRE(1)	Fire number for this surface node
(4)	16-20	LELEM(1)	Element number of one-dimensional isoparametric bar element adjacent to this surface node
	21-25	LI(2)	Node number of second boundary surface node.
	.	.	.
	.	.	.
	.	.	.
	.	.	.
	.	.	Continue until all (NS1) nodes are input, four nodes per card.

NOTES/

(1) See Fig. A.4(a)

(2) Specify which of the material descriptions input on Cards V.C above applies to this boundary node.

(3) A surface element can be subjected to one of four fires to be input later in the Time-Fire History Data Block.

(4) The area of the surface exposed to fire is taken to be the cross-sectional area of the one-dimensional bar element connected to that surface node, as shown in Fig. A.4(a). One-dimensional fire surface nodes can only be used in conjunction with one-dimensional bar elements.

3. Description of Two-Dimensional Fire Surface Segments (15I5)

Omit this card if (N2) on control card above is zero.

note	columns	variable	entry
(1)	1-5	LI(1)	Node number of segment end I for first surface segment
(1)	6-10	LJ(1)	Node number of segment end J for first surface segment
(2)	11-15	LMAT(1)	Material type for this surface segment LE. NBCMAT
(3)	16-20	LFIRE(1)	Fire number for this surface segment
(4)	20-25	LELEM(1)	Element number of two-dimensional quadrilateral or triangular element adjacent to this surface segment
	26-30	LI(2)	Node of number of segment end I for second surface segment
	.	.	.
	.	.	.
	.	.	.
	.	.	Continue until all (NS2) segments are input, three segments per card

NOTES/

(1) Surface segment runs from I to J, as shown in Fig. A.4(b)

(2) Specify which of the material descriptions input on Cards V.C above applies to this surface segment.

(3) A surface segment can be subjected to one of four fires to be input later in the Time-Fire History Data Block

(4) The edge of one of the quadrilateral elements lies between nodes I and J. Enter the number of that element so that its thickness may be used in determining the area of the surface exposed to fire. Two-dimensional fire surface segments can only be used in conjunction with two-dimensional isoparametric elements.

4. Description of Three-Dimensional Fire Surface Areas (12I5)

Omit this card if (N3) on control card above is zero.

note	columns	variable	entry
(1)	1-5	LI(1)	Node number of corner I for first surface element
(1)	6-10	LJ(1)	Node number of corner J for first surface element
(1)	11-15	LK(1)	Node number of corner K for first surface element
(1)	16-20	LL(1)	Node number of corner L for first surface element
(2)	21-25	LMAT(1)	Material type for this surface element LE. NBCMAT
(3)	26-30	LFIRE(1)	Fire number for this surface element
	31-35	LI(2)	Node number of corner I for second surface element
	.	.	.
	.	.	.
	.	.	.
	.	.	Continue until all (NS3) surface elements are input, two elements per card

NOTES/

(1) A surface area is defined by the four nodes, I, J, K, and L, as shown in Fig. A.4(c). These must be input in counter-clockwise order and lie in the same plane.

(2) Specify which of the material descriptions input on Cards V.C above applies to this surface area.

(3) A surface area can be subjected to one of four fires to be input later in the Time-Fire History Data Block

VI. INTERNAL HEAT GENERATION DATA

A. Control Card (Alphanumeric)

EXOTHERMIC, N1, N2, N3, N4

note	field	variable	entry
(1)	EXOTHERMIC	--	Enter the word "EXOTHERMIC"
(2)	N1	NINTID	Number of one-dimensional elements with internal heat generation
(2)	N2	NINT2D	Number of two-dimensional elements with internal heat generation
(2)	N3	NINT3D	Number of three-dimensional elements with internal heat generation
(3)	N4	NQINT	Number of different heating functions

NOTES/

(1) This is an alphanumeric control card with key word (EXOTHERMIC) and control parameters (N1, N2, N3, and N4), as shown in Fig. A.1.

If internal heat generation is not being considered, insert as control card "EXOTHERMIC, 0, 0, 0, 0" and go to Data Block VII.

(2) Enter how many of each type of element undergoes internal heating from processes such as hydration, combustion, etc.

(3) Enter the number of heat-rate vs. time functions to be considered.

B. Internal Heat Generation Functions

Input the following set of cards for each heating function:

1. Control Card (2I5)

note	columns	variable	entry
(1)	1-5	MK	Number of points used to define heating function GE.2
(2)	6-10	MT	Type of heating curve input EQ.0, heat flow per unit volume EQ.1, heat flow per unit mass

NOTES/

(1) Internal heating rate is input as a tabular function of time. At least two points are needed to define each function and linear interpolation is used between points.

(2) Heating rate may be defined as heat per unit time per unit volume or as heat per unit time per unit mass. Units must be compatible with other input data.

2. Heat Function (3E10.0)

note	columns	variable	entry
(1)	1-10	X(1)	Time of point 1
	11-20	Y(1)	Value of heat rate at point 1
	21-30	X(2)	Time of point 2
	.	.	.
	.	.	.
	.	.	.
	.	Y(MK)	Continue until all (MK) points are input

NOTE/

(1) Input the table that defines internal heating rate in the same way as conductivity, heat capacity and density in IV.B.2, 4 points per card.

C. Data for One-Dimensional Elements (16I5)

Omit this card if (N1) on control card is zero.

note	columns	variable	entry
	1-5	IEL(1)	Element number of first one-dimensional bar element undergoing internal heating.
	6-10	IMAT(1)	Heat function number for first element
	11-15	IEL(2)	Element number of second one-dimensional element undergoing internal heating
	16-20	IMAT(2)	Heat function number for second element
	.	.	.
	.	.	.
	.	.	.
	.	IMAT(NINT1D)	Continue until all (NINT1D) elements are input, 8 elements per card.

D. Data for Two-Dimensional Elements (16I5)

Omit this card if (N2) on Control Card is zero.

Input element number and heat function number for all (NINT2D) two-dimensional elements, 8 per card, in the same way as above.

E. Data for Three-Dimensional Elements (16I5)

Omit this card if (N3) on Control Card is zero.

Input element number and heat function number for all (NINT3D) three-dimensional elements, 8 per card, in the same way as above.

VII. CONVERGENCE CRITERIA

A. Control Card (Alphanumeric)

CONVERGENCE

note	field	variable	entry
(1)	CONVERGENCE	--	Enter the word "CONVERGENCE"

NOTE/

(1) This is an alphanumeric control card with key word (CONVERGENCE) and no control parameters, as in Fig. A.1.

B. Convergence Criteria Card (I5,2F10.0,I5,2F10.0)

note	columns	variable	entry
(1)	1-5	NCONV	Maximum number of iterations permitted for fire B.C. solution
(1)	6-15	CONV	Permissible relative error for fire B.C. iteration
(2)	16-25	BETA	Overconvergence factor for fire B.C. iteration
(3)	26-30	NCONU	Maximum number of iterations permitted for system solution in each time step EQ.0, linear solution - no iteration

note	columns	variable	entry
(3)	31-40	CONU	Permissible relative error for system iteration
(2)	41-50	ALPHA	Overconvergence factor for system iteration

NOTES/

(1) The fire boundary conditions are temperature-dependent and require an iterative solution process, controlled by variables (NCONV) and (CONV) as defined on page 27. If there are no fire B.C.s or if no iteration is desired, leave columns 1-25 blank.

(2) See page 27 . To ignore overconvergence factors, leave blank.

(3) When material properties (heat conductivity, etc.) are temperature-dependent, an iterative process is needed to solve the nonlinear heat flow problem. However, usually it suffices to forgo iteration when material properties change little during a time step, thereby reducing greatly computation costs. In this case (or for linear heat flow problems) leave columns 26-50 blank.

VIII. INITIAL CONDITIONS

A. Initial Time Step Control Card (A4,I6,2F10.0,2X,A3)

note	columns	variable	entry
	1-4	IA	Enter the word "STEP"
(1)	5-10	MDT	Initial number in sequencing of time steps
(1)	11-20	TIME	Initial time (i.e., base time)
(2)	21-30	TEMP	Uniform initial temperature (If initial temperature is nonuniform, leave cols. 21-30 blank and input nodal temperatures on the data card below)
	31-32	-	blank
(3)	33-34	JP	3-symbol alphanumeric code that will appear in columns 74-76 of punched output.

NOTES/

(1) The usual starting point for time step sequencing is "0" and the usual initial time is "0.0". However, nonzero values may be specified if desired.

(2) All nodal temperatures are initialized to this value unless its value is "0.0", in which case all initial nodal temperatures must be input on Card XIII.B below.

(3) If these columns are left blank the code "NODE" will appear on punched nodal temperatures and the code "ELEM" on punched element temperatures.

B. Initial Temperature Distribution Data (7(4X,F6.1))

Omit this card if (TEMP) on control card above is nonzero.

note	columns	variable	entry
(1)	1-4	--	blank
	5-10	T(1)	Initial temperature at node 1
	11-14	--	blank
	15-20	T(2)	Initial temperature at node 2
	.	.	.
	.	.	.
	.	.	.
	.		
	.	T(NUMNP)	Continue until all nodal points are input.

NOTE/

(1) Enter the initial nodal temperatures, seven (7) nodes per data card, using as many cards as necessary. This format is compatible with punched output from the program; hence, this option can be used to restart a previous analysis that must be continued for a longer time period. For a restarted analysis change the initial time (TIME) on the control card to the time at which the previous analysis ended.

IX. TIME-FIRE HISTORY

For each time step input the following block of data:

A. Time Step Control Card (A4,I6,F10.0,I5,4F10.0,4I3)

note	columns	variable	entry
	1-4	IA	Enter the word "STEP"
(1)	5-10	NDT	Time step number
(2)	11-20	DT	Time step interval
(3)	21-25	ITOF	Number of non-zero flow or temperature boundary conditions
(4)	26-35	TFIRE(1)	Temperature of fire 1
	36-45	TFIRE(2)	Temperature of fire 2
	46-55	TFIRE(3)	Temperature of fire 3
	56-65	TFIRE(4)	Temperature of fire 4
	66-68	I1	Printed output desired for this time step EQ.0, no output EQ.1, nodal temperatures EQ.2, element temperatures EQ.3, both nodal and element temperatures
	69-71	I2	Punched output desired for this time step EQ.0, no punched output EQ.1, nodal temperatures EQ.2, element temperatures EQ.3, both nodal and element temperatures
(5)	72-74	I6	Intermediate printed output for debugging purposes EQ.0, no printout EQ.1, debugging printout
(6)	75-77	I7	Fire boundary condition flag EQ.0, continue with same fire B.C. surfaces previously defined EQ.1, input new fire B.C. surface in Data Block IX.C below

NOTES/

(1) Time step cards must be input in ascending sequence with no time steps omitted.

(2) Input the length of the time step in the same units used to define other input quantities. To end a data case input a negative time step size in these columns and then proceed to the next data case (Heading Card).

(3) Enter the total number of nonzero fixed heat flow or fixed temperature boundary condition nodes. The value of flow or temperature for each of these nodes is entered on the next data card.

(4) Up to four fire histories can be defined for use in conjunction with the fire boundary conditions input in Data Block V. Enter the temperature of each fire at the end of the time step.

(5) If convergence difficulties are encountered in any particular analysis, this option may be called to print nodal temperatures during each iteration. This option can also be used to determine an efficient overconvergence factor.

(6) A fire boundary surface is defined in Data Block V and can be used for all time steps in the fire history. However, it is possible to change the fire surface during any time step by setting (I7) equal to "1" and inputting the new surface below. The new surface replaces the one previously input and is used for all subsequent time steps.

B. Nonzero Boundary Condition Data (5(I5,F10.0))

Omit this card if (ITOF) on Control Card above is zero.

note	columns	variable	entry
(1)	1-5	J(1)	Node number
	6-15	FT(1)	Specified temperature or flow at that node
	16-20	J(2)	Node number

note	columns	variable	entry
	21-30	FT(2)	Specified temperature or flow at that node
	.	.	.
	.	.	.
	.	.	.
	.		
	.	FT(ITOF)	Continue until all (ITOF) boundary nodes are input.

NOTE/

(1) Input the global node number and the specified temperature boundary condition or specified heat flow boundary condition for each of the (ITOF) boundary nodes. Enter five (5) nodes per data card and use as many cards as necessary. This data must be input for each time step - even if the boundary conditions do not change from time step to time step. Fixed flow nodes are differentiated from fixed temperature nodes using the information input previously in Data Block II.C.

C. Description of New Fire Surface

Omit these cards if (I7) on the control card above is zero.

1. Control Card (Alphanumeric)

   SURFACE, N1, N2, N3

   (Same format as Card V.D.1, page A-16)

2. Description of One-Dimensional Fire Surface Nodes (16I5)

   Omit this card if (N1) is zero

   (Same format as Card V.D.2, page A-17)

3. Description of Two-Dimensional Fire Surface Segments (15I5)

   Omit this card if (N2) is zero

   (Same format as Card V.D.3, page A-18)

4. Description of Three-Dimensional Fire Surface Areas (12I5)

Omit this card if (N3) is zero

(Same format as Card V.D.4, page A-19)

APPENDIX B

SAMPLE PROBLEMS

SAMPLE PROBLEM 1 - COLUMN CROSS-SECTION WITH UNIFORM FIRE EXPOSURE

The first sample problem is a two-dimensional thermal analysis of a square column (Fig. B.1) from the basement level of a typical reinforced concrete frame structure. It is necessary only to consider a quadrant of the column in the thermal analysis because of its cross-sectional symmetry and the uniformity of the intended fire exposure. The column is thus idealized by the finite element grid in Fig. B.2, where planes of symmetry are modeled as insulated ($Q_p = 0$) surfaces. The thermal properties used in both sample problems are those given by Bizri [3]. The choice of the grid was based on the results of previous studies. A fine grid is employed in the vicinity of the fire boundary since a steep temperature gradient is to be expected there. A coarser grid is used in the center of the column since the gradient there is expected to be lower. The steel bars have been idealized as rectangles based on an area equivalence (S = 0.89D). The flexibility of steel placement is apparent from Fig. B.2, allowing convenient modeling of any cross-section regardless of steel arrangement. The column is analyzed for two time-temperature curves (pseudo-fires):

1) A long duration moderate intensity fire (ASTM E-119), and

2) A short duration high intensity fire (SDHI).

These two pseudo-fire curves are shown in Figs. B.3 and B.4, respectively.

The fire boundary condition is simulated with the nonlinear model using a concrete emissivity of 0.9 and a flame emissivity of 0.3. Input data for this problem is given in Table B.1 (for the first few time steps), and typical output is given in Table B.2. Figs. B.3 and B.4 are graphs showing the results of the analysis as the variation of temperature with time for certain elements, the exterior corner element (78) and the interior corner element (1), two steel elements (60 and 8), and a side element (10). The ASTM fire was also considered using a flame emissivity of 0.9 (Fig. B.5). The importance of flame emissivity can be seen by comparing Figs. B.3 and B.5. The central processing time required for each case is 49 seconds using the University of California CDC 6400 computer.

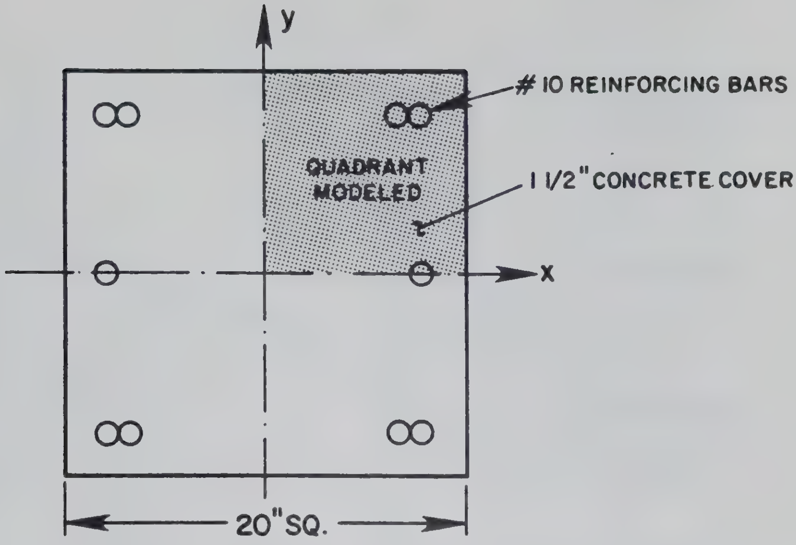


FIGURE B.1 COLUMN CROSS-SECTION

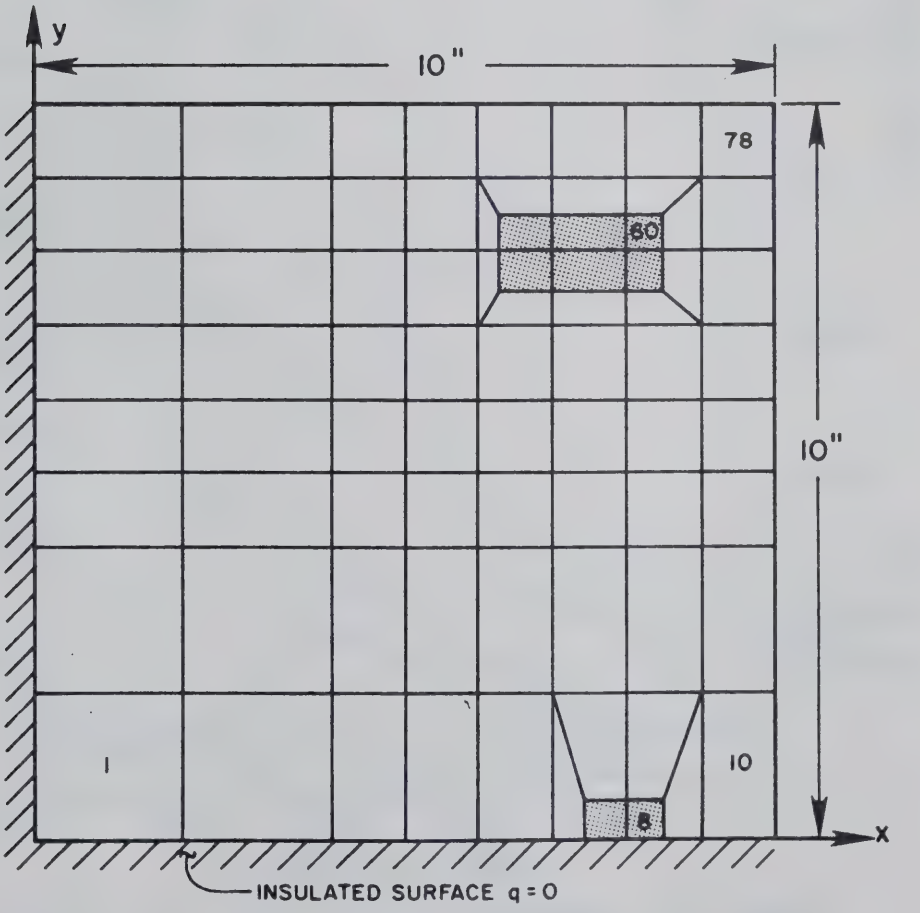


FIGURE B.2 FINITE ELEMENT MESH FOR COLUMN QUADRANT
(TWO-DIMENSIONAL QUADRILATERAL ELEMENTS)

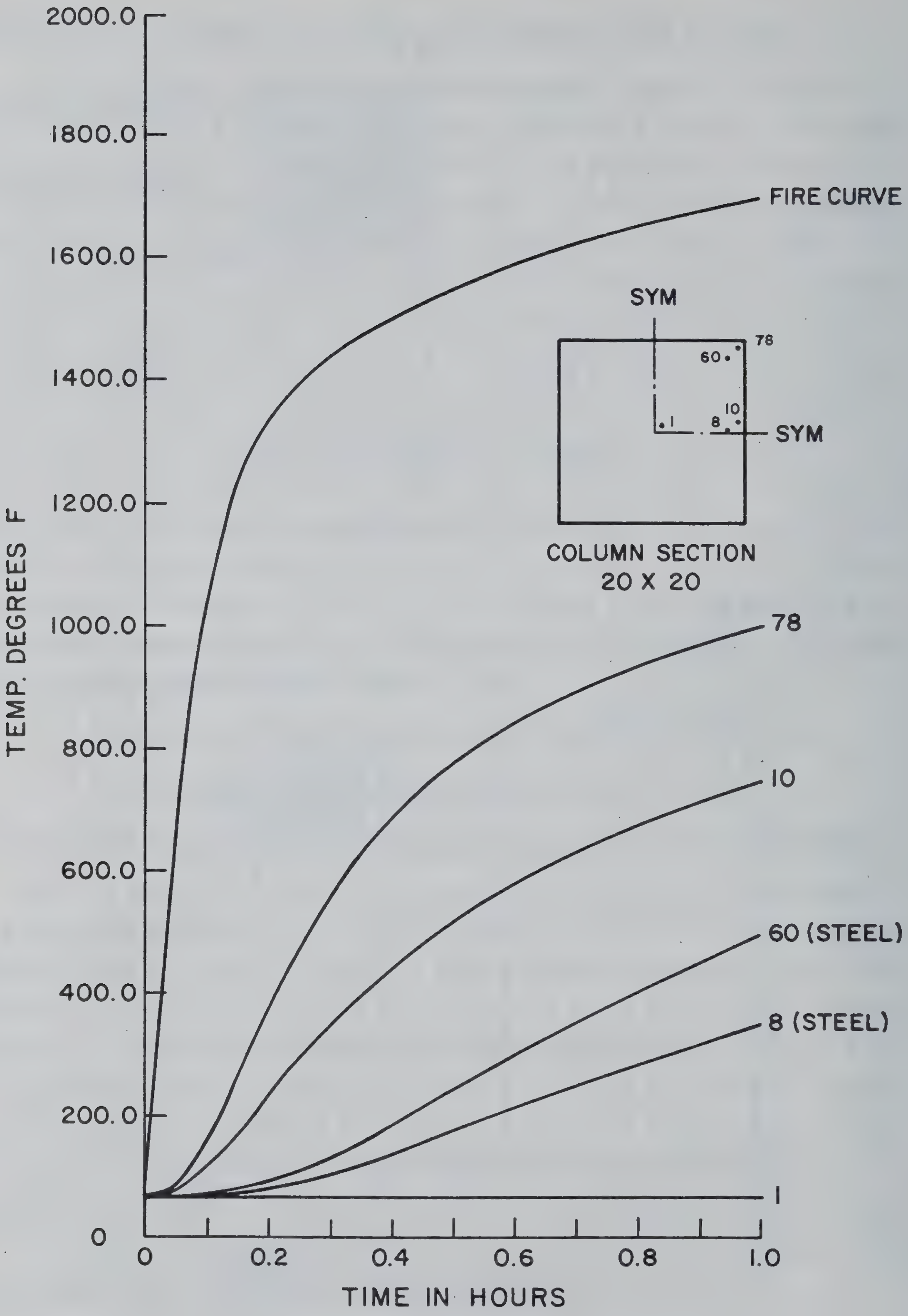


FIGURE B.3 TEMPERATURE HISTORIES FOR SELECT ELEMENTS IN COLUMN UNIFORMLY EXPOSED TO ASTM FIRE ($\varepsilon_f = 0.3$)

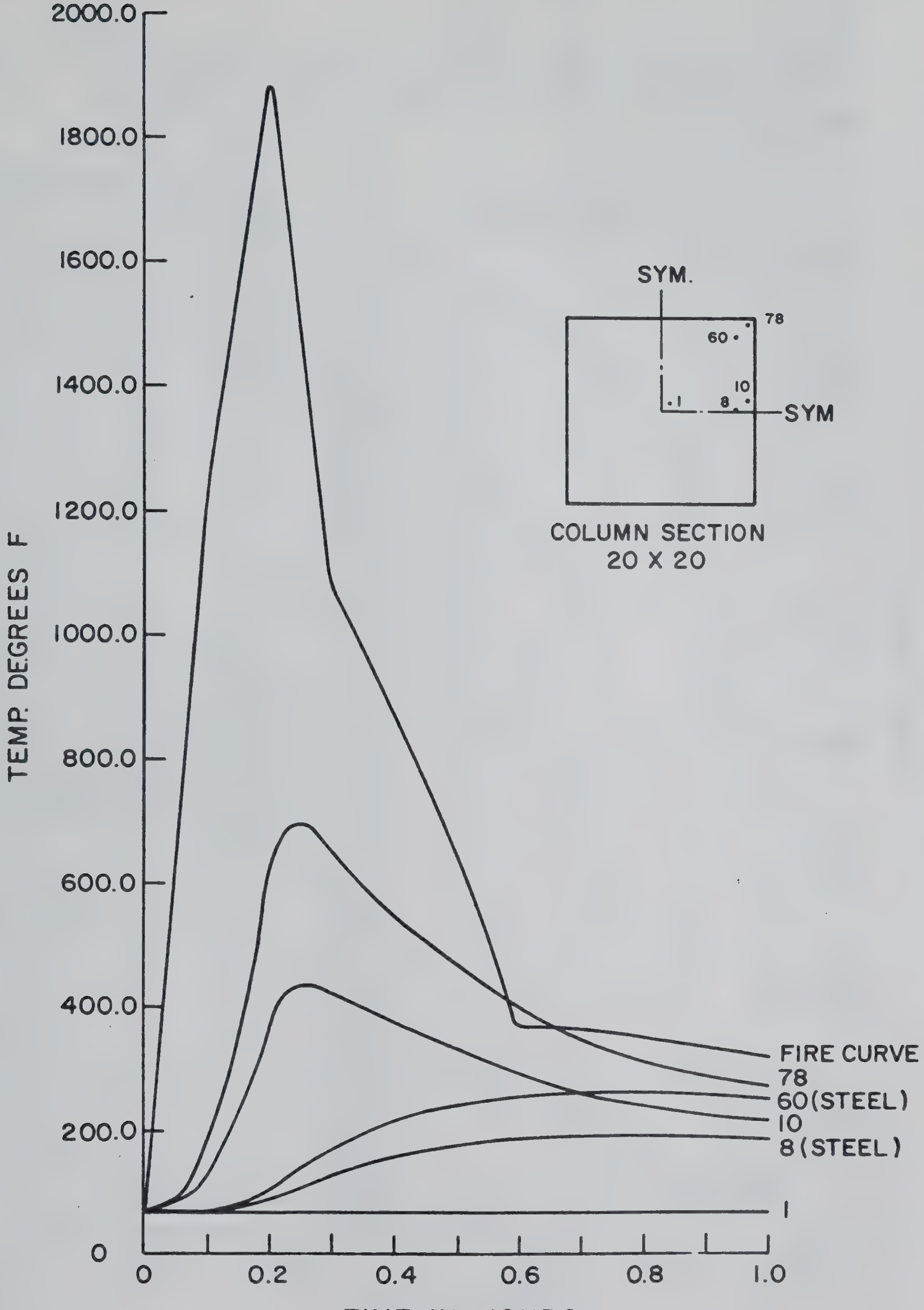


FIGURE B.4 TEMPERATURE HISTORIES FOR SELECT ELEMENTS IN COLUMN UNIFORMLY EXPOSED TO SDHI FIRE ($\varepsilon_f = 0.3$)

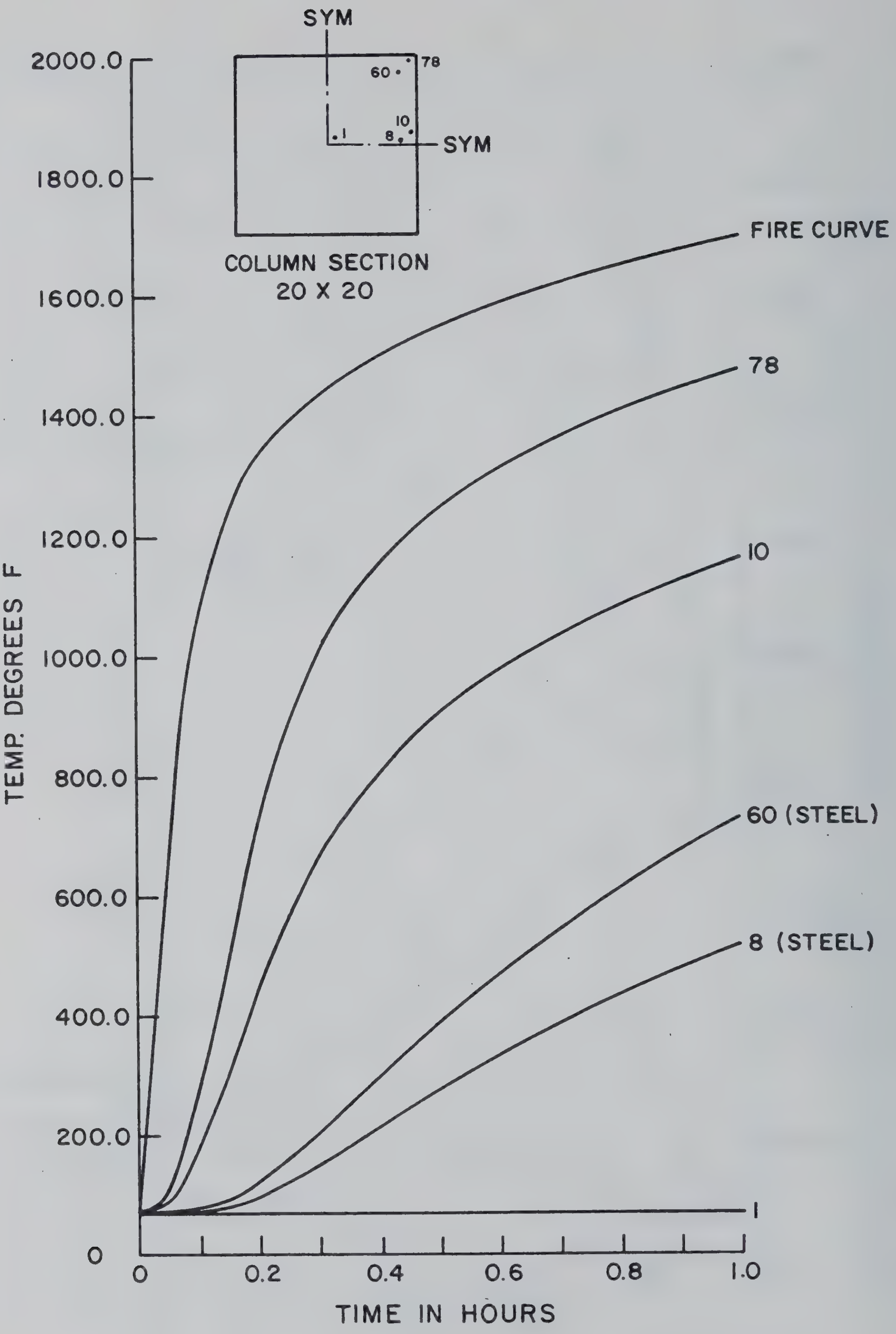


FIGURE B.5 TEMPERATURE HISTORIES FOR SELECT ELEMENTS IN COLUMN UNIFORMLY EXPOSED TO ASTM FIRE ($\varepsilon_f = 0.9$)

```
         10        20        30        40        50        60
 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***
NODES,96,0
    1        0.        0.
    3   .333333        0.
    6   .583333        0.
    7   .614154        0.
    8   .666667        0.
    9   .708333        0.
   10   .750000        0.
   11   .833333        0.
   12   .614154   .047086
   13   .666667   .047086
   14   .708333   .047086
   15        0.   .166667
   17   .333333   .166667
   23   .833333   .166667
   24        0.   .333333
   26   .333333   .333333
   32   .833333   .333333
   33        0.   .416667
   35   .333333   .416667
   41   .833333   .416667
   42        0.   .500000
   44   .333333   .500000
   50   .833333   .500000
   51        0.   .583333
   53   .333333   .583333
   55   .500000   .583333
   56   .520834   .614154
   57   .583333   .583333
   58   .583333   .614154
   59   .666667   .583333
   60   .666667   .614154
   61   .708333   .614154
   62   .750000   .583333
   63   .833333   .583333
   64        0.   .666667
   66   .333333   .666667
   68   .500000   .666667
   69   .520834   .666667
   70   .583333   .666667
   71   .666667   .666667
   72   .708333   .666667
   73   .750000   .666667
   74   .833333   .666667
   75        0.   .750000
   77   .333333   .750000
   79   .500000   .750000
   80   .520834   .708333
   81   .583333   .750000
   82   .583333   .708333
   83   .666667   .750000
   84   .666667   .708333
   85   .708333   .708333
   86   .750000   .750000
         10        20        30        40        50        60
```

TABLE B.1 INPUT FOR SAMPLE PROBLEM ONE

```
        10        20        30        40        50        60        70        80
   87   .833333   .750000
   88        0.   .833333
   90   .333333   .833333
   96   .833333   .833333
ELEMENTS,0,78,0
    1    1    2   16   15    1       1.0
    6    6    7   12   20    1       1.0
    7    7    8   13   12    2       1.0
    9    9   10   22   14    1       1.0
   10   10   11   23   22    1       1.0
   11   12   13   21   20    1       1.0
   12   13   14   22   21    1       1.0
   13   15   16   25   24    1       1.0
   21   24   25   34   33    1       1.0
   29   33   34   43   42    1       1.0
   37   42   43   52   51    1       1.0
   41   46   47   57   55    1       1.0
   42   47   48   59   57    1       1.0
   43   48   49   62   59    1       1.0
   44   49   50   63   62    1       1.0
   45   51   52   65   64    1       1.0
   50   55   57   58   56    1       1.0
   51   57   59   60   58    1       1.0
   52   59   62   61   60    1       1.0
   53   61   62   73   72    1       1.0
   54   62   63   74   73    1       1.0
   55   56   58   70   69    2       1.0
   56   58   60   71   70    2       1.0
   57   60   61   72   71    2       1.0
   58   69   70   82   80    2       1.0
   59   70   71   84   82    2       1.0
   60   71   72   85   84    2       1.0
   61   64   65   76   75    1       1.0
   66   80   82   81   79    1       1.0
   67   82   84   83   81    1       1.0
   68   84   85   86   83    1       1.0
   69   72   73   86   85    1       1.0
   71   75   76   89   88    1       1.0
   75   79   81   93   92    1       1.0
   76   81   83   94   93    1       1.0
   77   83   86   95   94    1       1.0
   78   86   87   96   95    1       1.0
MATERIALS,2
    4    0    0
       0.0      1.01     390.0      1.01    1650.0     0.506    3000.0    0.506
     0.272
     150.0
    3    4    0
       0.0     30.00    1100.0     19.90    3000.0     19.90
       0.0     0.107     750.0     0.144    1100.0     0.172    3000.0     0.172
     480.0
FIRE,0,16,0,1
NONLINEAR
    1.7E-9     460.0
       .27      1.25       1.0       0.9       0.3       0.9
SURFACE,0,16,0
        10        20        30        40        50        60        70        80
```

```
         10        20        30        40        50        60        70        80
   11   23    1    1   10   23   32    1    1   20   32   41    1    1   28
   41   50    1    1   36   50   63    1    1   44   63   74    1    1   54
   74   87    1    1   70   87   96    1    1   78   96   95    1    1   78
   95   94    1    1   77   94   93    1    1   76   93   92    1    1   75
   92   91    1    1   74   91   90    1    1   73   90   89    1    1   72
   89   88    1    1   71
EXOTHERMIC,0,0,0,0
CONVERGENCE
   15      .005      -.25
STEP     0       0.0      68.0
STEP     1      .025        347.600                                3  2
STEP     2      .025        627.200                                3  2
STEP     3      .025        906.800                                3  2
STEP     4      .025       1060.000                                3  2
STEP     5      .025       1150.000                                3  2
         10        20        30        40        50        60        70        80
```

```
************************************************************


    FFFFF  I  RRRRR  EEEEE  SSSSS          TTTTT  33333
    F      I  R   R  E      S                T       3
    F      I  R   R  E      S                T      3
    F      I  R   R  E      S                T     3
    FFF    I  RRRRR  EEE    SSSSS  =====     T    3333
    F      I  RR     E          S            T        3
    F      I  R R    E          S            T        3
    F      I  R  R   E          S            T        3
    F      I  R   R  EEEEE  SSSSS            T    33333


      A THERMAL ANALYZER FOR THREE-DIMENSIONAL SYSTEMS,
      WITH TEMPERATURE-DEPENDENT THERMAL PROPERTIES,
      SUBJECTED TO A FIRE ENVIRONMENT


************************************************************


                 - - - TITLE OF RUN - - -

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***


************************************************************
```

TABLE B.2 OUTPUT FOR SAMPLE PROBLEM ONE

```
*****************************************************************

   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

     GEOMETRIC DESCRIPTION OF SYSTEM TO BE ANALYZED

*****************************************************************


 . . . . THERE ARE    96 NODAL POINTS . . . .


NODAL                          COORDINATES                  BOUNDARY
POINT         X                Y                Z          CONDITION

   1         0.               0.              -0.               FLOW
   2          .1667           0.               0.               FLOW
   3          .3333           0.              -0.               FLOW
   4          .4167           0.               0.               FLOW
   5          .5000           0.               0.               FLOW
   6          .5833           0.              -0.               FLOW
   7          .6142           0.              -0.               FLOW
   8          .6667           0.              -0.               FLOW
   9          .7083           0.              -0.               FLOW
  10          .7500           0.              -0.               FLOW
  11          .8333           0.              -0.               FLOW
  12          .6142            .0471          -0.               FLOW
  13          .6667            .0471          -0.               FLOW
  14          .7083            .0471          -0.               FLOW
  15         0.                .1667          -0.               FLOW
  16          .1667            .1667           0.               FLOW
  17          .3333            .1667          -0.               FLOW
  18          .4167            .1667           0.               FLOW
  19          .5000            .1667           0.               FLOW
  20          .5833            .1667           0.               FLOW
  21          .6667            .1667           0.               FLOW
  22          .7500            .1667           0.               FLOW
  23          .8333            .1667          -0.               FLOW
  24         0.                .3333          -0.               FLOW
  25          .1667            .3333           0.               FLOW
  26          .3333            .3333          -0.               FLOW
  27          .4167            .3333           0.               FLOW
  28          .5000            .3333           0.               FLOW
  29          .5833            .3333           0.               FLOW
  30          .6667            .3333           0.               FLOW
  31          .7500            .3333           0.               FLOW
  32          .8333            .3333          -0.               FLOW
  33         0.                .4167          -0.               FLOW
  34          .1667            .4167           0.               FLOW
  35          .3333            .4167          -0.               FLOW
  36          .4167            .4167           0.               FLOW
  37          .5000            .4167           0.               FLOW
  38          .5833            .4167           0.               FLOW
```

```
39          .6667        .4167       0.        FLOW
40          .7500        .4167       0.        FLOW
41          .8333        .4167      -0.        FLOW
42         0.            .5000      -0.        FLOW
43          .1667        .5000       0.        FLOW
44          .3333        .5000      -0.        FLOW
45          .4167        .5000       0.        FLOW
46          .5000        .5000       0.        FLOW
47          .5833        .5000       0.        FLOW
48          .6667        .5000       0.        FLOW
49          .7500        .5000       0.        FLOW
50          .8333        .5000      -0.        FLOW
51         0.            .5833      -0.        FLOW
52          .1667        .5833       0.        FLOW
53          .3333        .5833      -0.        FLOW
54          .4167        .5833       0.        FLOW
55          .5000        .5833      -0.        FLOW
56          .5208        .6142      -0.        FLOW
57          .5833        .5833      -0.        FLOW
58          .5833        .6142      -0.        FLOW
59          .6667        .5833      -0.        FLOW
60          .6667        .6142      -0.        FLOW
61          .7083        .6142      -0.        FLOW
62          .7500        .5833      -0.        FLOW
63          .8333        .5833      -0.        FLOW
64         0.            .6667      -0.        FLOW
65          .1667        .6667       0.        FLOW
66          .3333        .6667      -0.        FLOW
67          .4167        .6667       0.        FLOW
68          .5000        .6667      -0.        FLOW
69          .5208        .6667      -0.        FLOW
70          .5833        .6667      -0.        FLOW
71          .6667        .6667      -0.        FLOW
72          .7083        .6667      -0.        FLOW
73          .7500        .6667      -0.        FLOW
74          .8333        .6667      -0.        FLOW
75         0.            .7500      -0.        FLOW
76          .1667        .7500       0.        FLOW
77          .3333        .7500      -0.        FLOW
78          .4167        .7500       0.        FLOW
79          .5000        .7500      -0.        FLOW
80          .5208        .7083      -0.        FLOW
81          .5833        .7500      -0.        FLOW
82          .5833        .7083      -0.        FLOW
83          .6667        .7500      -0.        FLOW
84          .6667        .7083      -0.        FLOW
85          .7083        .7083      -0.        FLOW
86          .7500        .7500      -0.        FLOW
87          .8333        .7500      -0.        FLOW
88         0.            .8333      -0.        FLOW
89          .1667        .8333       0.        FLOW
90          .3333        .8333      -0.        FLOW
91          .4167        .8333       0.        FLOW
92          .5000        .8333       0.        FLOW
93          .5833        .8333       0.        FLOW
94          .6667        .8333       0.        FLOW
```

```
   95            .7500           .8333        0.          FLOW
   96            .8333           .8333       -0.          FLOW


 . . . . THERE ARE    78  2-D ELEMENTS . . . .

ELMT      I     J     K     L   MAT       THICKNESS

    1     1     2    16    15     1         1.00000
    2     2     3    17    16     1         1.00000
    3     3     4    18    17     1         1.00000
    4     4     5    19    18     1         1.00000
    5     5     6    20    19     1         1.00000
    6     6     7    12    20     1         1.00000
    7     7     8    13    12     2         1.00000
    8     8     9    14    13     2         1.00000
    9     9    10    22    14     1         1.00000
   10    10    11    23    22     1         1.00000
   11    12    13    21    20     1         1.00000
   12    13    14    22    21     1         1.00000
   13    15    16    25    24     1         1.00000
   14    16    17    26    25     1         1.00000
   15    17    18    27    26     1         1.00000
   16    18    19    28    27     1         1.00000
   17    19    20    29    28     1         1.00000
   18    20    21    30    29     1         1.00000
   19    21    22    31    30     1         1.00000
   20    22    23    32    31     1         1.00000
   21    24    25    34    33     1         1.00000
   22    25    26    35    34     1         1.00000
   23    26    27    36    35     1         1.00000
   24    27    28    37    36     1         1.00000
   25    28    29    38    37     1         1.00000
   26    29    30    39    38     1         1.00000
   27    30    31    40    39     1         1.00000
   28    31    32    41    40     1         1.00000
   29    33    34    43    42     1         1.00000
   30    34    35    44    43     1         1.00000
   31    35    36    45    44     1         1.00000
   32    36    37    46    45     1         1.00000
   33    37    38    47    46     1         1.00000
   34    38    39    48    47     1         1.00000
   35    39    40    49    48     1         1.00000
   36    40    41    50    49     1         1.00000
   37    42    43    52    51     1         1.00000
   38    43    44    53    52     1         1.00000
   39    44    45    54    53     1         1.00000
   40    45    46    55    54     1         1.00000
   41    46    47    57    55     1         1.00000
   42    47    48    59    57     1         1.00000
   43    48    49    62    59     1         1.00000
   44    49    50    63    62     1         1.00000
   45    51    52    65    64     1         1.00000
   46    52    53    66    65     1         1.00000
```

```
47    53    54    67    66     1           1.00000
48    54    55    68    67     1           1.00000
49    55    56    69    68     1           1.00000
50    55    57    58    56     1           1.00000
51    57    59    60    58     1           1.00000
52    59    62    61    60     1           1.00000
53    61    62    73    72     1           1.00000
54    62    63    74    73     1           1.00000
55    56    58    70    69     2           1.00000
56    58    60    71    70     2           1.00000
57    60    61    72    71     2           1.00000
58    69    70    82    80     2           1.00000
59    70    71    84    82     2           1.00000
60    71    72    85    84     2           1.00000
61    64    65    76    75     1           1.00000
62    65    66    77    76     1           1.00000
63    66    67    78    77     1           1.00000
64    67    68    79    78     1           1.00000
65    68    69    80    79     1           1.00000
66    80    82    81    79     1           1.00000
67    82    84    83    81     1           1.00000
68    84    85    86    83     1           1.00000
69    72    73    86    85     1           1.00000
70    73    74    87    86     1           1.00000
71    75    76    89    88     1           1.00000
72    76    77    90    89     1           1.00000
73    77    78    91    90     1           1.00000
74    78    79    92    91     1           1.00000
75    79    81    93    92     1           1.00000
76    81    83    94    93     1           1.00000
77    83    86    95    94     1           1.00000
78    86    87    96    95     1           1.00000


 . . . MAXIMUM BANDWIDTH IS   16 . . .
```

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*****************************************************************

   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

   THERMAL PROPERTIES OF SYSTEM TO BE ANALYZED

   THERE ARE   2 DIFFERENT MATERIALS

*****************************************************************



 . . . . MATERIAL NUMBER     1  . . . .


      . . . CONDUCTIVITY . . .

   NODE    TEMPERATURE       VALUE        SLOPE

      1          0.          1.010
                                        0.
      2        390.0         1.010
                                        -.400E-03
      3       1650.0          .506
                                        0.
      4       3000.0          .506


      . . . SPECIFIC HEAT . . .

 MATERIAL PARAMETER OF CONSTANT VALUE     .272


      . . . DENSITY . . .

 MATERIAL PARAMETER OF CONSTANT VALUE 150.000



 . . . . MATERIAL NUMBER     2  . . . .


      . . . CONDUCTIVITY . . .

   NODE    TEMPERATURE       VALUE        SLOPE

      1          0.         30.000
                                        -.918E-02
      2       1100.0        19.900
                                        0.
      3       3000.0        19.900
```

```
    . . . SPECIFIC HEAT . . .

 NODE     TEMPERATURE        VALUE       SLCFE

    1          0.             .107
                                           .493E-04
    2        750.0            .144
                                           .800E-04
    3       1100.0            .172
                                          0.
    4       3000.0            .172


    . . . DENSITY . . .

MATERIAL PARAMETER OF CONSTANT VALUE 48C.CCC
```

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*************************************************************

    FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

    NON-LINEAR FIRE BOUNDARY CONDITION

*************************************************************


Q=A*(TF-TS)**N+SB*V*(AB*EF*(TF+TSHIFT)**4-ES*(TS+TSHIFT)**4)


WHERE
     TF - PSUEDO FIRE TEMPERATURE
     TS - SURFACE TEMPERATURE
     SB - STEFAN BOLZTMANN CONSTANT =     .1700E-08
     TSHIFT - SHIFT TO ABSOLUTE TEMPERATURE SCALE =     460.0
AND


MAT  CONVECT  CONVECT     VIEW  ABSORBT     FIRE  SURFACE
NUM   FACTOR    POWER   FACTOR           EMISSIV  EMISSIV
         (A)      (N)      (V)     (AE)     (EF)     (ES)

  1     .270    1.250    1.000     .900     .300     .900



 . . . THERE ARE  16 2-D SURFACE ELEMENTS EXPOSED TO FIRE . .


        DESCRIPTION OF SURFACE DIRECTLY EXPOSED TO FIRE

FIREBC    NODE    NODE    MAT    FIRE      AREA
SURFACE      I       J   TYPE    TYPE

     1      11      23      1       1      .167
     2      23      32      1       1      .167
     3      32      41      1       1      .083
     4      41      50      1       1      .083
     5      50      63      1       1      .083
     6      63      74      1       1      .083
     7      74      87      1       1      .083
     8      87      96      1       1      .083
     9      96      95      1       1      .083
    10      95      94      1       1      .083
    11      94      93      1       1      .083
    12      93      92      1       1      .083
    13      92      91      1       1      .083
    14      91      90      1       1      .083
    15      90      89      1       1      .167
    16      89      88      1       1      .167
```

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*************************************************************

   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

   INFORMATION RELEVANT TO THE ANALYSIS PROCEDURE

*************************************************************



 . . . . CONVERGENCE CRITERIA . . . .


 CONVERGENCE CRITERIA FOR BOUNDARY CONDITIONS

    PERMISSIBLE ERROR =     .00500
    MAXIMUM NUMBER OF ITERATIONS =   15      BETA =    -.2500



 . . . . STORAGE REQUIREMENT FOR BLANK COMMON . . . .

    SIZE BLANK COMMON =        3390 (DECIMAL)
                      =     0006476 (OCTAL)
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**********************************************************

    FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

INITIAL SEQUENCE NUMBER IS    0 AND INITIAL TIME IS      0.

**********************************************************


------------ NODAL POINT TEMPERATURES ---------------


    N     TEMP.       N     TEMP.       N     TEMP.       N     TEMP.
    1     68.00       2     68.00       3     68.00       4     68.00
    5     68.00       6     68.00       7     68.00       8     68.00
    9     68.00      10     68.00      11     68.00      12     68.00
   13     68.00      14     68.00      15     68.00      16     68.00
   17     68.00      18     68.00      19     68.00      20     68.00
   21     68.00      22     68.00      23     68.00      24     68.00
   25     68.00      26     68.00      27     68.00      28     68.00
   29     68.00      30     68.00      31     68.00      32     68.00
   33     68.00      34     68.00      35     68.00      36     68.00
   37     68.00      38     68.00      39     68.00      40     68.00
   41     68.00      42     68.00      43     68.00      44     68.00
   45     68.00      46     68.00      47     68.00      48     68.00
   49     68.00      50     68.00      51     68.00      52     68.00
   53     68.00      54     68.00      55     68.00      56     68.00
   57     68.00      58     68.00      59     68.00      60     68.00
   61     68.00      62     68.00      63     68.00      64     68.00
   65     68.00      66     68.00      67     68.00      68     68.00
   69     68.00      70     68.00      71     68.00      72     68.00
   73     68.00      74     68.00      75     68.00      76     68.00
   77     68.00      78     68.00      79     68.00      80     68.00
   81     68.00      82     68.00      83     68.00      84     68.00
   85     68.00      86     68.00      87     68.00      88     68.00
   89     68.00      90     68.00      91     68.00      92     68.00
   93     68.00      94     68.00      95     68.00      96     68.00
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   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

 TIME STEP NUMBER     1 - TIME     .025 - TIME STEP     .025

******************************************************************

    NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS    -0

    FIRE BOUNDARY CONDITION
     FIRE(1) =     347.600
     FIRE(2) =       -0.
     FIRE(3) =       -0.
     FIRE(4) =       -0.


------------ NODAL POINT TEMPERATURES ---------------


     N      TEMP.       N      TEMP.       N      TEMP.       N      TEMP.
     1      68.00       2      68.00       3      68.00       4      68.00
     5      68.00       6      68.01       7      68.03       8      68.03
     9      68.04      10      68.47      11      72.74      12      68.02
    13      68.03      14      68.05      15      68.00      16      68.00
    17      68.00      18      68.00      19      68.00      20      68.00
    21      68.03      22      68.37      23      72.73      24      68.00
    25      68.00      26      68.00      27      68.00      28      68.00
    29      68.00      30      68.03      31      68.36      32      72.73
    33      68.00      34      68.00      35      68.00      36      68.00
    37      68.00      38      68.00      39      68.03      40      68.36
    41      72.73      42      68.00      43      68.00      44      68.00
    45      68.00      46      68.00      47      68.00      48      68.03
    49      68.36      50      72.73      51      68.00      52      68.00
    53      68.00      54      68.00      55      68.01      56      68.04
    57      68.01      58      68.04      59      68.03      60      68.06
    61      68.08      62      68.37      63      72.73      64      68.03
    65      68.03      66      68.03      67      68.03      68      68.02
    69      68.05      70      68.05      71      68.07      72      68.07
    73      68.47      74      72.76      75      68.36      76      68.36
    77      68.36      78      68.36      79      68.37      80      68.07
    81      68.43      82      68.06      83      68.45      84      68.07
    85      68.10      86      68.73      87      73.05      88      72.73
    89      72.73      90      72.73      91      72.73      92      72.73
    93      72.74      94      72.76      95      73.05      96      77.32


------------- TEMPERATURE OF 2-D ELEMENTS ------------


     N      TEMP.       N      TEMP.       N      TEMP.       N      TEMP.
     1      68.00       2      68.00       3      68.00       4      68.00
     5      68.00       6      68.01       7      68.03       8      68.04
```

```
  9     68.23      10     70.58      11     68.02      12     68.12
 13     68.00      14     68.00      15     68.00      16     68.00
 17     68.00      18     68.01      19     68.20      20     70.55
 21     68.00      22     68.00      23     68.00      24     68.00
 25     68.00      26     68.01      27     68.19      28     70.54
 29     68.00      30     68.00      31     68.00      32     68.00
 33     68.00      34     68.01      35     68.19      36     70.54
 37     68.00      38     68.00      39     68.00      40     68.00
 41     68.01      42     68.02      43     68.20      44     70.55
 45     68.01      46     68.01      47     68.01      48     68.01
 49     68.03      50     68.03      51     68.04      52     68.13
 53     68.25      54     70.58      55     68.05      56     68.06
 57     68.07      58     68.06      59     68.06      60     68.08
 61     68.19      62     68.19      63     68.19      64     68.20
 65     68.13      66     68.23      67     68.25      68     68.34
 69     68.34      70     70.75      71     70.54      72     70.54
 73     70.54      74     70.55      75     70.57      76     70.60
 77     70.75      78     73.04

. . . . PUNCHING ELEMENT DATA . . . .

  0 SYSTEM ITERATIONS WERE PERFORMED
  3 B. C. ITERATIONS WERE PERFORMED
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   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

 TIME STEP NUMBER    2 - TIME    .050 - TIME STEP    .025

************************************************************

    NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS   -0

    FIRE BOUNDARY CONDITION
     FIRE(1) =     627.200
     FIRE(2) =      -0.
     FIRE(3) =      -0.
     FIRE(4) =      -0.


------------ NODAL POINT TEMPERATURES ---------------


     N       TEMP.       N       TEMP.      N       TEMP.       N       TEMP.
     1       68.00       2       68.00      3       68.00       4       68.00
     5       68.00       6       68.04      7       68.15       8       68.20
     9       68.24      10       70.27     11       87.40      12       68.14
    13       68.19      14       68.29     15       68.00      16       68.00
    17       68.00      18       68.00     19       68.00      20       68.02
    21       68.16      22       69.81     23       87.37      24       68.00
    25       68.00      26       68.00     27       68.00      28       68.00
    29       68.01      30       68.16     31       69.78      32       87.35
    33       68.00      34       68.00     35       68.00      36       68.00
    37       68.00      38       68.01     39       68.16      40       69.78
    41       87.35      42       68.00     43       68.00      44       68.00
    45       68.00      46       68.00     47       68.02      48       68.16
    49       69.78      50       87.35     51       68.01      52       68.01
    53       68.01      54       68.01     55       68.05      56       68.23
    57       68.08      58       68.26     59       68.15      60       68.34
    61       68.42      62       69.85     63       87.38      64       68.16
    65       68.16      66       68.16     67       68.16      68       68.13
    69       68.28      70       68.30     71       68.37      72       68.42
    73       70.28      74       87.51     75       69.78      76       69.78
    77       69.78      78       69.78     79       69.83      80       68.36
    81       70.11      82       68.33     83       70.22      84       68.41
    85       68.55      86       71.61     87       88.92      88       87.35
    89       87.35      90       87.35     91       87.35      92       87.37
    93       87.40      94       87.52     95       88.91      96      105.94


------------- TEMPERATURE OF 2-D ELEMENTS ------------


     N       TEMP.       N       TEMP.      N       TEMP.       N       TEMP.
     1       68.00       2       68.00      3       68.00       4       68.00
     5       68.02       6       68.09      7       68.17       8       68.23
   9      69.15     10      78.71     11      68.12     12      68.61
  13      68.00     14      68.00     15      68.00     16      68.00
  17      68.01     18      68.09     19      68.98     20      78.58
  21      68.00     22      68.00     23      68.00     24      68.00
  25      68.01     26      68.09     27      68.97     28      78.56
  29      68.00     30      68.00     31      68.00     32      68.00
  33      68.01     34      68.09     35      68.97     36      78.57
  37      68.01     38      68.01     39      68.01     40      68.02
  41      68.04     42      68.10     43      68.99     44      78.59
  45      68.09     46      68.09     47      68.09     48      68.09
  49      68.17     50      68.15     51      68.21     52      68.69
  53      69.24     54      78.75     55      68.27     56      68.32
  57      68.39     58      68.32     59      68.35     60      68.44
  61      68.97     62      68.97     63      68.97     64      68.98
  65      68.65     66      69.16     67      69.27     68      69.70
  69      69.71     70      79.58     71      78.56     72      78.56
  73      78.56     74      78.58     75      78.68     76      78.81
  77      79.57     78      88.84

. . . . PUNCHING ELEMENT DATA . . . .


  0 SYSTEM ITERATIONS WERE PERFORMED
  3 B. C. ITERATIONS WERE PERFORMED
```

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   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

 TIME STEP NUMBER    3 - TIME     .075 - TIME STEP     .025

****************************************************************

    NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS    -0

    FIRE BOUNDARY CONDITION
     FIRE(1) =     906.800
     FIRE(2) =       -0.
     FIRE(3) =       -0.
     FIRE(4) =       -0.


------------ NODAL POINT TEMPERATURES ---------------


    N     TEMP.        N     TEMP.        N     TEMP.        N     TEMP.
    1     68.00        2     68.00        3     68.00        4     68.00
    5     68.01        6     68.16        7     68.52        8     68.66
    9     68.79       10     74.58       11    117.37       12     68.47
   13     68.63       14     68.95       15     68.00       16     68.00
   17     68.00       18     68.00       19     68.01       20     68.06
   21     68.53       22     73.37       23    117.27       24     68.00
   25     68.00       26     68.00       27     68.00       28     68.01
   29     68.05       30     68.54       31     73.27       32    117.21
   33     68.00       34     68.00       35     68.00       36     68.00
   37     68.01       38     68.05       39     68.54       40     73.28
   41    117.21       42     68.01       43     68.01       44     68.01
   45     68.01       46     68.02       47     68.07       48     68.55
   49     73.28       50    117.22       51     68.05       52     68.05
   53     68.05       54     68.05       55     68.18       56     68.78
   57     68.29       58     68.90       59     68.54       60     69.13
   61     69.37       62     73.45       63    117.32       64     68.54
   65     68.54       66     68.54       67     68.54       68     68.46
   69     68.94       70     69.00       71     69.24       72     69.37
   73     74.66       74    117.73       75     73.27       76     73.27
   77     73.27       78     73.28       79     73.39       80     69.19
   81     74.15       82     69.10       83     74.52       84     69.35
   85     69.75       86     78.60       87    121.75       88    117.21
   89    117.21       90    117.21       91    117.22       92    117.28
   93    117.36       94    117.77       95    121.75       96    163.90


-------------- TEMPERATURE OF 2-D ELEMENTS -------------


    N     TEMP.        N     TEMP.        N     TEMP.        N     TEMP.
    1     68.00        2     68.00        3     68.00        4     68.01
    5     68.06        6     68.30        7     68.57        8     68.76
```

```
  9     71.42     10     95.65     11     68.42     12     69.87
 13     68.00     14     68.00     15     68.00     16     68.00
 17     68.03     18     68.30     19     70.93     20     95.28
 21     68.00     22     68.00     23     68.00     24     68.00
 25     68.03     26     68.30     27     70.91     28     95.24
 29     68.00     30     68.00     31     68.00     32     68.01
 33     68.04     34     68.30     35     70.91     36     95.25
 37     68.03     38     68.03     39     68.03     40     68.06
 41     68.14     42     68.36     43     70.96     44     95.32
 45     68.30     46     68.30     47     68.30     48     68.31
 49     68.59     50     68.54     51     68.72     52     70.12
 53     71.71     54     95.79     55     68.90     56     69.07
 57     69.28     58     69.06     59     69.17     60     69.42
 61     70.91     62     70.91     63     70.91     64     70.92
 65     70.00     66     71.46     67     71.78     68     73.05
 69     73.09     70     98.19     71     95.24     72     95.24
 73     95.25     74     95.29     75     95.55     76     95.95
 77     98.16     78    121.50


. . . . PUNCHING ELEMENT DATA . . . .


  0 SYSTEM ITERATIONS WERE PERFORMED
  3 B. C. ITERATIONS WERE PERFORMED
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******************************************************************

    FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

 TIME STEP NUMBER    4 - TIME    .100 - TIME STEP    .025

******************************************************************

     NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS   -0

     FIRE BOUNDARY CONDITION
      FIRE(1) =    1060.000
      FIRE(2) =      -0.
      FIRE(3) =      -0.
      FIRE(4) =      -0.


------------ NODAL POINT TEMPERATURES ---------------


    N     TEMP.       N      TEMP.       N      TEMP.       N      TEMP.
    1     68.00       2      68.00       3      68.00       4      68.00
    5     68.03       6      68.43       7      69.29       8      69.59
    9     69.86      10      81.66      11     156.38      12      69.18
   13     69.54      14      70.21      15      68.00      16      68.00
   17     68.00      18      68.00      19      68.02      20      68.17
   21     69.29      22      79.41      23     156.16      24      68.00
   25     68.00      26      68.00      27      68.00      28      68.02
   29     68.15      30      69.32      31      79.23      32     156.02
   33     68.00      34      68.00      35      68.00      36      68.00
   37     68.02      38      68.15      39      69.32      40      79.24
   41    156.02      42      68.02      43      68.02      44      68.02
   45     68.03      46      68.06      47      68.19      48      69.35
   49     79.26      50     156.05      51      68.15      52      68.15
   53     68.15      54      68.15      55      68.48      56      69.95
   57     68.78      58      70.22      59      69.38      60      70.73
   61     71.23      62      79.56      63     156.27      64      69.32
   65     69.32      66      69.32      67      69.33      68      69.21
   69     70.28      70      70.43      71      70.96      72      71.23
   73     82.00      74     157.24      75      79.23      76      79.23
   77     79.23      78      79.24      79      79.40      80      70.81
   81     80.89      82      70.64      83      81.71      84      71.20
   85     72.03      86      90.37      87     165.46      88     156.02
   89    156.02      90     156.02      91     156.03      92     156.16
   93    156.36      94     157.32      95     165.44      96     238.09


-------------- TEMPERATURE OF 2-D ELEMENTS -------------


    N     TEMP.       N      TEMP.       N      TEMP.       N      TEMP.
    1     68.00       2      68.00       3      68.00       4      68.02
    5     68.16       6      68.76       7      69.40       8      69.80
```

```
  9     75.29     10    118.40     11     69.04     12     72.11
 13     68.00     14     68.00     15     68.00     16     68.01
 17     68.09     18     68.73     19     74.31     20    117.70
 21     68.00     22     68.00     23     68.00     24     68.01
 25     68.08     26     68.74     27     74.28     28    117.63
 29     68.01     30     68.01     31     68.01     32     68.03
 33     68.10     34     68.75     35     74.29     36    117.64
 37     68.08     38     68.08     39     68.09     40     68.18
 41     68.38     42     68.92     43     74.39     44    117.78
 45     68.73     46     68.73     47     68.74     48     68.79
 49     69.48     50     69.36     51     69.78     52     72.73
 53     76.01     54    118.77     55     70.22     56     70.58
 57     71.04     58     70.54     59     70.80     60     71.35
 61     74.28     62     74.28     63     74.28     64     74.30
 65     72.43     66     75.44     67     76.11     68     78.83
 69     78.91     70    123.77     71    117.62     72    117.63
 73    117.63     74    117.71     75    118.20     76    119.07
 77    123.71     78    164.84

. . . . PUNCHING ELEMENT DATA . . . .


 0 SYSTEM ITERATIONS WERE PERFORMED
 3 B. C. ITERATIONS WERE PERFORMED
```

```
*************************************************************

   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 *** INTERIOR BASEMENT COLUMN - BLDG STUDY - ASTM FIRE ***

 TIME STEP NUMBER     5 - TIME     .125 - TIME STEP     .025

*************************************************************

    NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS    -0

    FIRE BOUNDARY CONDITION
     FIRE(1) =     1150.000
     FIRE(2) =       -0.
     FIRE(3) =       -0.
     FIRE(4) =       -0.


------------ NODAL POINT TEMPERATURES ---------------


    N      TEMP.        N      TEMP.        N      TEMP.        N      TEMP.
    1      68.00        2      68.00        3      68.00        4      68.01
    5      68.08        6      68.94        7      70.59        8      71.13
    9      71.59       10      91.21       11     199.03       12      70.38
   13      71.04       14      72.19       15      68.00       16      68.00
   17      68.00       18      68.01       19      68.06       20      68.37
   21      70.58       22      87.87       23     198.64       24      68.00
   25      68.00       26      68.00       27      68.01       28      68.04
   29      68.32       30      70.64       31      87.60       32     198.41
   33      68.00       34      68.00       35      68.01       36      68.01
   37      68.05       38      68.34       39      70.63       40      87.60
   41     198.41       42      68.04       43      68.04       44      68.04
   45      68.07       46      68.14       47      68.43       48      70.71
   49      87.65       50     198.46       51      68.32       52      68.33
   53      68.33       54      68.35       55      69.06       56      71.93
   57      69.69       58      72.43       59      70.85       60      73.35
   61      74.21       62      88.10       63     198.87       64      70.62
   65      70.62       66      70.63       67      70.66       68      70.56
   69      72.53       70      72.80       71      73.75       72      74.23
   73      92.09       74     200.71       75      87.60       76      87.60
   77      87.60       78      87.61       79      87.74       80      73.43
   81      90.11       82      73.16       83      91.64       84      74.16
   85      75.59       86     106.61       87     214.40       88     198.40
   89     198.40       90     198.40       91     198.43       92     198.65
   93     199.02       94     200.84       95     214.37       96     317.37


-------------- TEMPERATURE OF 2-D ELEMENTS -------------


    N      TEMP.        N      TEMP.        N      TEMP.        N      TEMP.
    1      68.00        2      68.00        3      68.00        4      68.04
    5      68.36        6      69.57        7      70.78        8      71.48
```

```
  9     80.71     10    144.19     11     70.09     12     75.42
 13     68.00     14     68.00     15     68.00     16     68.03
 17     68.20     18     69.48     19     79.17     20    143.13
 21     68.00     22     68.00     23     68.01     24     68.03
 25     68.19     26     69.48     27     79.12     28    143.00
 29     68.02     30     68.02     31     68.03     32     68.07
 33     68.24     34     69.53     35     79.15     36    143.03
 37     68.18     38     68.18     39     68.20     40     68.41
 41     68.83     42     69.92     43     79.33     44    143.27
 45     69.47     46     69.48     47     69.49     48     69.66
 49     71.02     50     70.78     51     71.58     52     76.63
 53     82.16     54    144.94     55     72.42     56     73.08
 57     73.88     58     72.98     59     73.46     60     74.43
 61     79.11     62     79.11     63     79.12     64     79.14
 65     76.06     66     81.11     67     82.27     68     87.00
 69     87.13     70    153.45     71    143.00     72    143.00
 73    143.01     74    143.11     75    143.88     76    145.40
 77    153.36     78    213.19


. . . . PUNCHING ELEMENT DATA . . . .


  0 SYSTEM ITERATIONS WERE PERFORMED
  3 B. C. ITERATIONS WERE PERFORMED
```

SAMPLE PROBLEM 2 - COLUMN WITH SPIRAL

The second sample problem is a circular column with longitudinal and spiral reinforcing which is uniformly exposed to fire. The dimensions and configuration of the column are shown in Fig. B.6. The column is subjected to each of the two fire curves discussed in the previous sample problem, the ASTM E-119 long-duration, moderate intensity fire (Fig. B.3) and the SDHI short-duration, high intensity fire (Fig. B.4). The fire boundary is modeled nonlinearly as in the previous sample problem. Both material properties and the boundary properties are given in the sample output in Table B.4.

For each fire curve two analyses are made:

1. A three-dimensional thermal analysis which is capable of modeling the effect spiral reinforcing has on heat flow into the column's interior. Due to symmetry only the wedge-shaped portion shown in Fig. B.6 need be discretized into elements. The mesh chosen is shown in Fig. B.7. Both the input data (Table B.3) and the output (Table B.4) is given for the first three time steps of the SDHI fire analysis. The temperature distribution within the column after one hour of fire exposure is shown in Fig. B.8.
2. A two-dimensional thermal analysis which ignores the effect of the spiral steel on heat flow into the column's interior. A mesh of two-dimensional quadrilateral elements which is equivalent to the three-dimensional mesh is defined by the top surface of the wedge-shaped mesh in Fig. B.7. The temperature distribution within the column after one hour of fire exposure is shown in Fig. B.9.

The time-temperature history of the longitudinal reinforcing bars is shown in Fig. B.10 for each of the four analyses conducted. Note that the steel spiral does considerably affect heat conduction into the interior of the column.

The SDHI fire analyses required 80 time steps for two hours duration. The three-dimensional analysis needed 902 seconds of central processing time (CDC 6400) and the two-dimensional analysis 62 seconds. For the ASTM fire, 120 time steps were needed for a two hour analysis. The three-dimensional case consumed 1520 seconds of central processing time and the two-dimensional case 105 seconds.

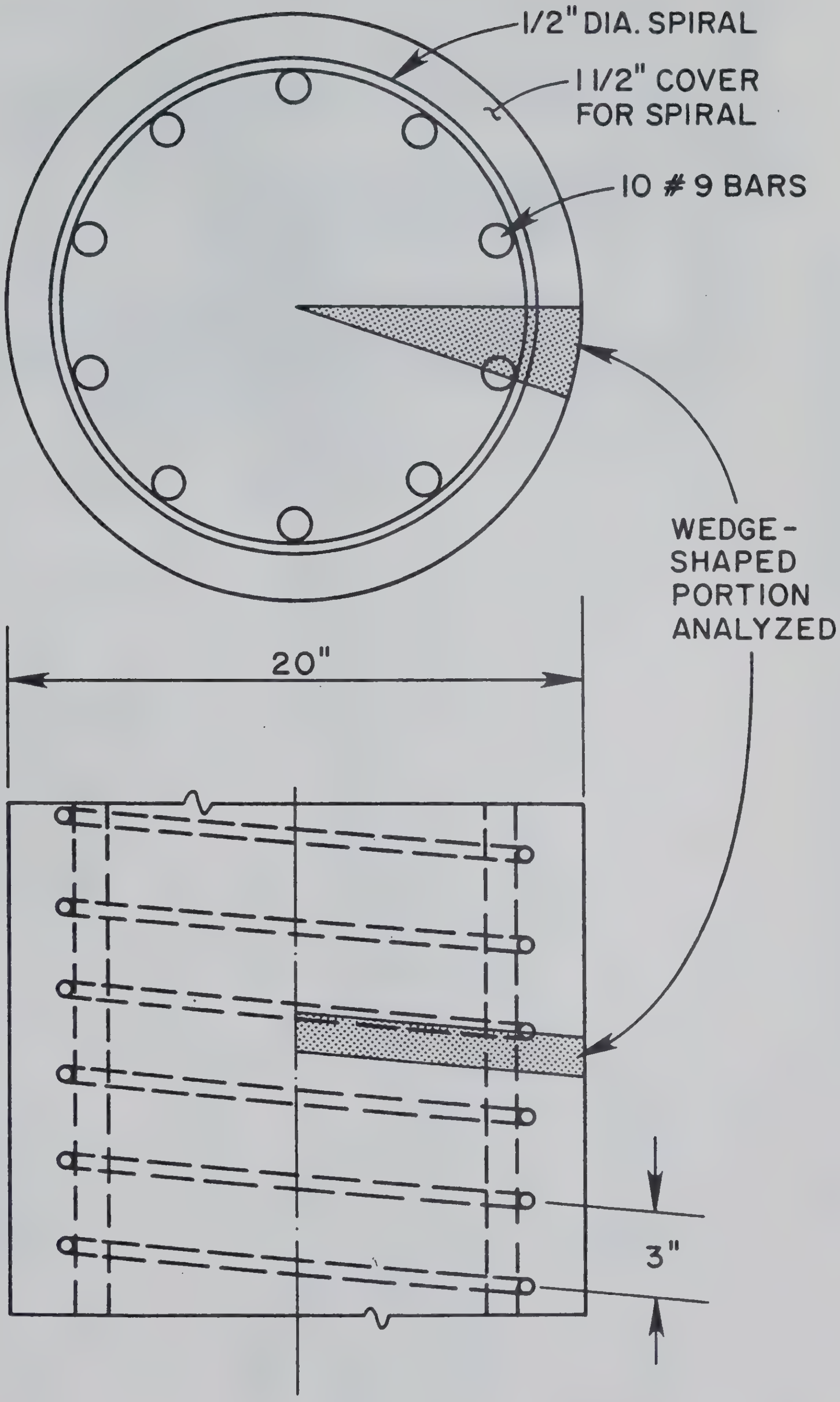


FIGURE B.6 CROSS-SECTIONS OF CIRCULAR COLUMN

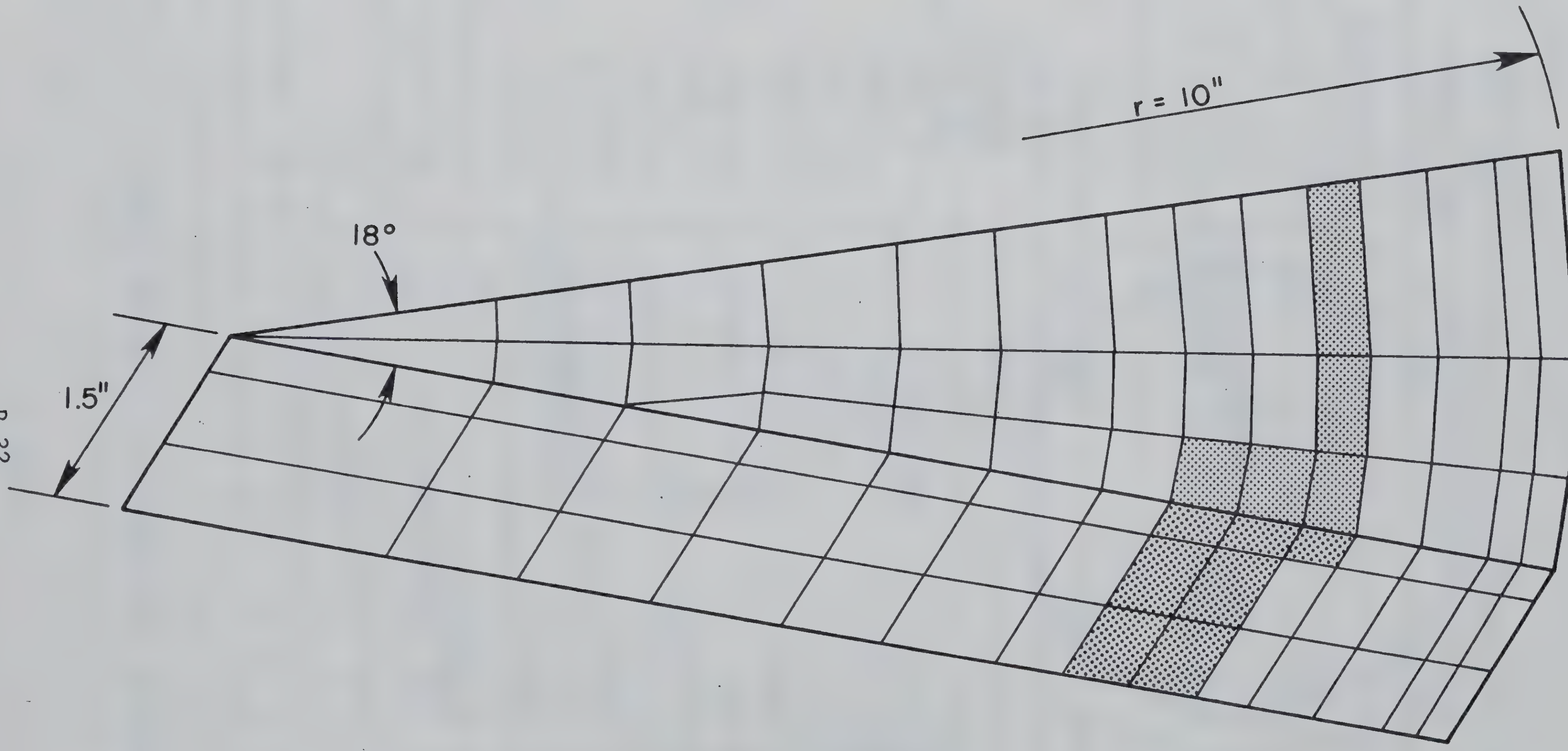
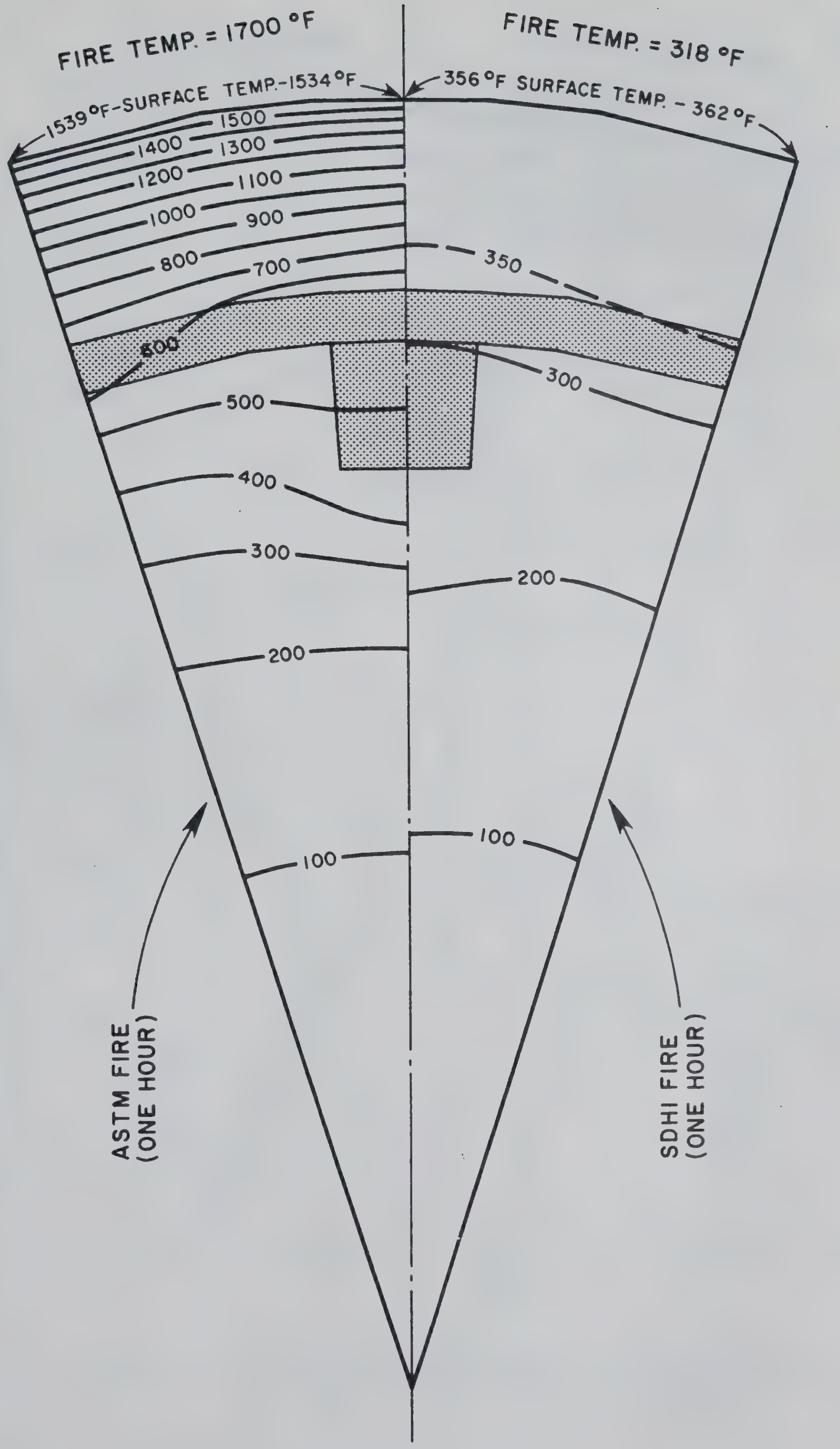


FIGURE B.7 THREE-DIMENSIONAL MESH FOR CIRCULAR COLUMN (WEDGE)



(ISOTHERMS PLOTTED FOR CROSS-SECTION THROUGH SPIRAL)

FIGURE B.8 ISOTHERMS IN CROSS-SECTION - THREE-DIMENSIONAL ANALYSIS WHICH INCLUDES EFFECT OF SPIRAL REINFORCING

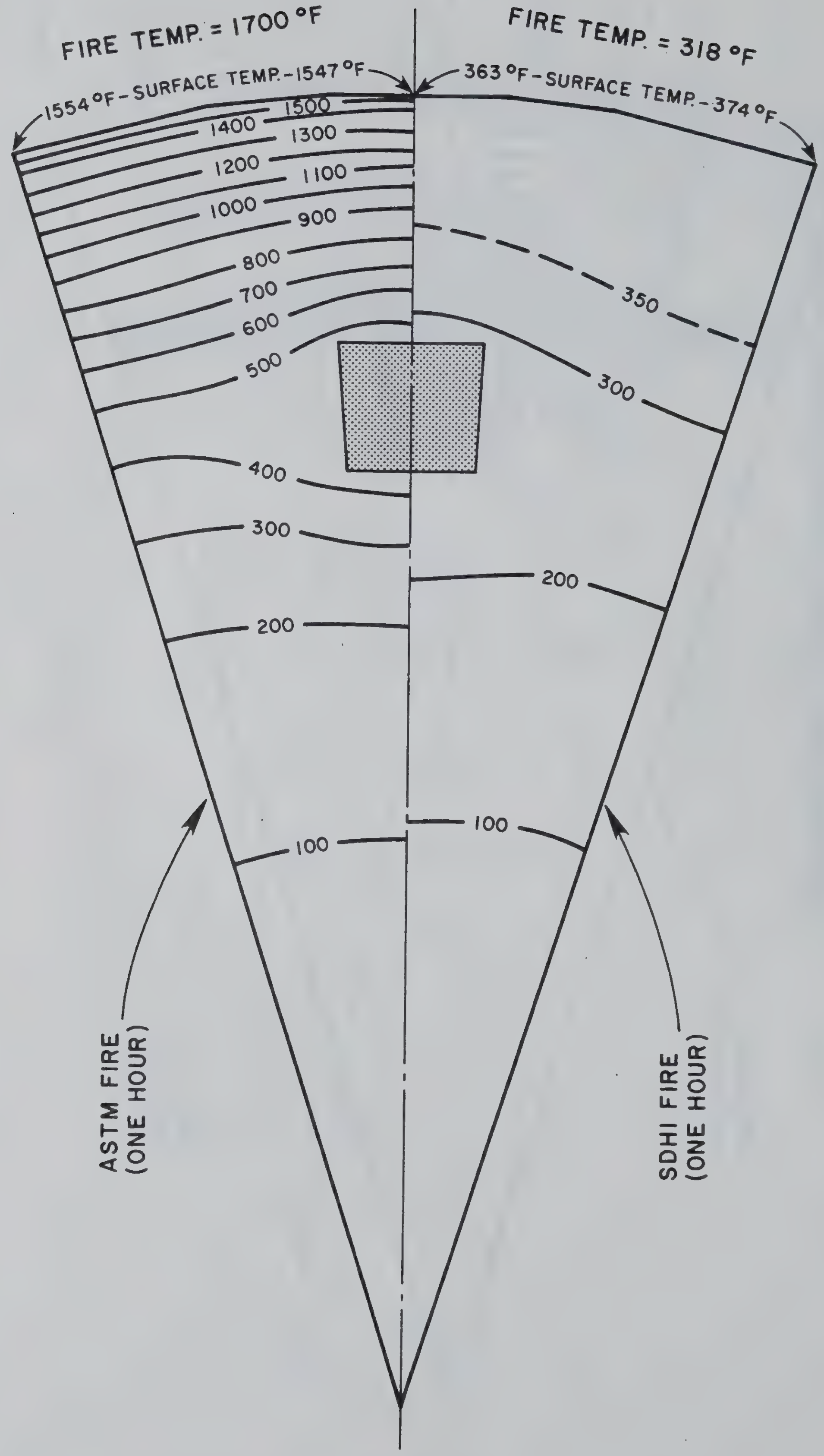


FIGURE B.9 ISOTHERMS IN CROSS-SECTION - TWO-DIMENSIONAL ANALYSIS WHICH IGNORES EFFECT OF SPIRAL REINFORCING

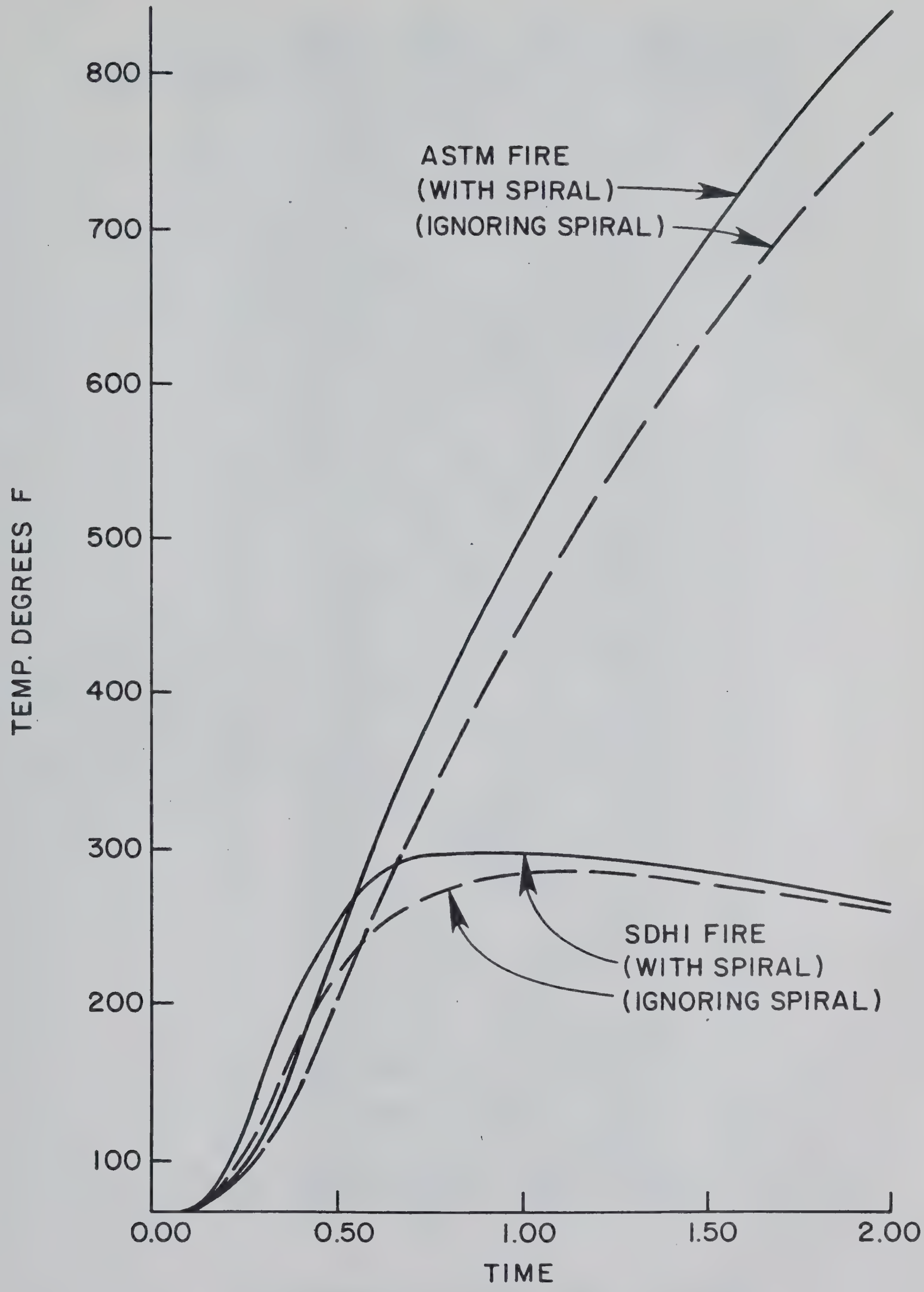


FIGURE B.10 TEMPERATURE-TIME HISTORY IN REINFORCING BARS
(AT CENTER OF BAR AT LEVEL OF SPIRAL)

```
         10        20        30        40
 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **
NODES,220,0
    1    0.        0.        0.
    3    0.        0.         .1042
    4    0.        0.         .1250
    5     .1646    -.0261    0.
    7     .1646    -.0261     .1042
    8     .1646    -.0261     .1250
    9     .1667    0.        0.
   11     .1667    0.         .1042
   12     .1667    0.         .1250
   13     .1646     .0261    0.
   15     .1646     .0261     .1042
   16     .1646     .0261     .1250
   17     .2469    -.0391    0.
   19     .2469    -.0391     .1042
   20     .2469    -.0391     .1250
   21     .2500    0.        0.
   23     .2500    0.         .1042
   24     .2500    0.         .1250
   25     .2469     .0391    0.
   27     .2469     .0391     .1042
   28     .2469     .0391     .1250
   29     .3292    -.0522    0.
   31     .3292    -.0522     .1042
   32     .3292    -.0522     .1250
   33     .3320    -.0302    0.
   35     .3320    -.0302     .1042
   36     .3320    -.0302     .1250
   37     .3333    0.        0.
   39     .3333    0.         .1042
   40     .3333    0.         .1250
   41     .3292     .0522    0.
   43     .3292     .0522     .1042
   44     .3292     .0522     .1250
   45     .4115    -.0652    0.
   47     .4115    -.0652     .1042
   48     .4115    -.0652     .1250
   49     .4149    -.0377    0.
   51     .4149    -.0377     .1042
   52     .4149    -.0377     .1250
   53     .4167    0.        0.
   55     .4167    0.         .1042
   56     .4167    0.         .1250
   57     .4115     .0652    0.
   59     .4115     .0652     .1042
   60     .4115     .0652     .1250
   61     .4733    -.0749    0.
   63     .4733    -.0749     .1042
   64     .4733    -.0749     .1250
   65     .4772    -.0434    0.
   67     .4772    -.0434     .1042
   68     .4772    -.0434     .1250
   69     .4792    0.        0.
   71     .4792    0.         .1042
         10        20        30        40
```

TABLE B.3 INPUT FOR SAMPLE PROBLEM TWO

```
         10        20        30        40
      72 .4792     0.                .1250
      73 .4733      .0749           0.
      75 .4733      .0749            .1042
      76 .4733      .0749            .1250
      77 .5350     -.0848           0.
      79 .5350     -.0848            .1042
      80 .5350     -.0848            .1250
      81 .5394     -.0492           0.
      83 .5394     -.0492            .1042
      84 .5394     -.0492            .1250
      85 .5417     0.               0.
      87 .5417     0.                .1042
      88 .5417     0.                .1250
      89 .5350      .0848           0.
      91 .5350      .0848            .1042
      92 .5350      .0848            .1250
      93 .5850     -.0927           0.
      95 .5850     -.0927            .1042
      96 .5850     -.0927            .1250
      97 .5899     -.0537           0.
      99 .5899     -.0537            .1042
     100 .5899     -.0537            .1250
     101 .5923     0.               0.
     103 .5923     0.                .1042
     104 .5923     0.                .1250
     105 .5850      .0927           0.
     107 .5850      .0927            .1042
     108 .5850      .0927            .1250
     109 .6262     -.0992           0.
     111 .6262     -.0992            .1042
     112 .6262     -.0992            .1250
     113 .6314     -.0575           0.
     115 .6314     -.0575            .1042
     116 .6314     -.0575            .1250
     117 .6340     0.               0.
     119 .6340     0.                .1042
     120 .6340     0.                .1250
     121 .6262      .0992           0.
     123 .6262      .0992            .1042
     124 .6262      .0992            .1250
     125 .6673     -.1057           0.
     127 .6673     -.1057            .1042
     128 .6673     -.1057            .1250
     129 .6729     -.0613           0.
     131 .6729     -.0613            .1042
     132 .6729     -.0613            .1250
     133 .6757     0.               0.
     135 .6757     0.                .1042
     136 .6757     0.                .1250
     137 .6673      .1057           0.
     139 .6673      .1057            .1042
     140 .6673      .1057            .1250
     141 .6996     -.1108           0.
     143 .6996     -.1108            .1042
     144 .6996     -.1108            .1250
     145 .7054     -.0642           0.
         10        20        30        40
         10        20        30        40
  147     .7054    -.0642    .1042
  148     .7054    -.0642    .1250
  149     .7083    0.       0.
  151     .7083    0.         .1042
  152     .7083    0.         .1250
  153     .6996     .1108   0.
  155     .6996     .1108    .1042
  156     .6996     .1108    .1250
  157     .7408    -.1173   0.
  159     .7408    -.1173    .1042
  160     .7408    -.1173    .1250
  161     .7469    -.0680   0.
  163     .7469    -.0680    .1042
  164     .7469    -.0680    .1250
  165     .7500    0.       0.
  167     .7500    0.         .1042
  168     .7500    0.         .1250
  169     .7408     .1173   0.
  171     .7408     .1173    .1042
  172     .7408     .1173    .1250
  173     .7819    -.1238   0.
  175     .7819    -.1238    .1042
  176     .7819    -.1238    .1250
  177     .7884    -.0718   0.
  179     .7884    -.0718    .1042
  180     .7884    -.0718    .1250
  181     .7917    0.       0.
  183     .7917    0.         .1042
  184     .7917    0.         .1250
  185     .7819     .1238   0.
  187     .7819     .1238    .1042
  188     .7819     .1238    .1250
  189     .8025    -.1271   0.
  191     .8025    -.1271    .1042
  192     .8025    -.1271    .1250
  193     .8092    -.0737   0.
  195     .8092    -.0737    .1042
  196     .8092    -.0737    .1250
  197     .8125    0.       0.
  199     .8125    0.         .1042
  200     .8125    0.         .1250
  201     .8025     .1271   0.
  203     .8025     .1271    .1042
  204     .8025     .1271    .1250
  205     .8231    -.1303   0.
  207     .8231    -.1303    .1042
  208     .8231    -.1303    .1250
  209     .8299    -.0756   0.
  211     .8299    -.0756    .1042
  212     .8299    -.0756    .1250
  213     .8333    0.       0.
  215     .8333    0.         .1042
  216     .8333    0.         .1250
  217     .8231     .1303   0.
  219     .8231     .1303    .1042
  220     .8231     .1303    .1250
         10        20        30        40
```

```
ELEMENTS,0,0,120
    1    1    5    9    9    2    6   10   10    1
    4    1    9   13   13    2   10   14   14    1
    7    5   17   21    9    6   18   22   10    1
   10    9   21   25   13   10   22   26   14    1
   13   17   29   33   33   18   30   34   34    1
   16   17   33   37   21   18   34   38   22    1
   19   21   37   41   25   22   38   42   26    1
   22   29   45   49   33   30   46   50   34    1
   25   33   49   53   37   34   50   54   38    1
   28   37   53   57   41   38   54   58   42    1
   31   45   61   65   49   46   62   66   50    1
   34   49   65   69   53   50   66   70   54    1
   37   53   69   73   57   54   70   74   58    1
   40   61   77   81   65   62   78   82   66    1
   43   65   81   85   69   66   82   86   70    1
   46   69   85   89   73   70   86   90   74    1
   49   77   93   97   81   78   94   98   82    1
   52   81   97  101   85   82   98  102   86    1
   55   85  101  105   89   86  102  106   90    1
   58   93  109  113   97   94  110  114   98    2
   61   97  113  117  101   98  114  118  102    1
   64  101  117  121  105  102  118  122  106    1
   67  109  125  129  113  110  126  130  114    2
   70  113  129  133  117  114  130  134  118    1
   73  117  133  137  121  118  134  138  122    1
   76  125  141  145  129  126  142  146  130    1
   78  127  143  147  131  128  144  148  132    2
   79  129  145  149  133  130  146  150  134    1
   81  131  147  151  135  132  148  152  136    2
   82  133  149  153  137  134  150  154  138    1
   84  135  151  155  139  136  152  156  140    2
   85  141  157  161  145  142  158  162  146    1
   88  145  161  165  149  146  162  166  150    1
   91  149  165  169  153  150  166  170  154    1
   94  157  173  177  161  158  174  178  162    1
   97  161  177  181  165  162  178  182  166    1
  100  165  181  185  169  166  182  186  170    1
  103  173  189  193  177  174  190  194  178    1
  106  177  193  197  181  178  194  198  182    1
  109  181  197  201  185  182  198  202  186    1
  112  189  205  209  193  190  206  210  194    1
  115  193  209  213  197  194  210  214  198    1
  118  197  213  217  201  198  214  218  202    1
  120  199  215  219  203  200  216  220  204    1
MATERIALS,2
    4    0    0
       0.0      0.90     390.0      0.90    1650.0     0.506    3000.0     0.506
     0.272
     150.0
    3    4    0
       0.0     30.00    1100.0     19.90    3000.0     19.90
       0.0     0.107     750.0     0.144    1100.0     0.172    3000.0     0.172
     480.0
FIRE,0,0,9,1
NONLINEAR
```

```
    1.7E-9     460.0
       .27      1.25       1.0       0.9       0.9       0.9
SURFACE,0,0,9
  205  209  210  206    1    1  206  210  211  207    1    1
  207  211  212  208    1    1  209  213  214  210    1    1
  210  214  215  211    1    1  211  215  216  212    1    1
  213  217  218  214    1    1  214  218  219  215    1    1
  215  219  220  216    1    1
EXOTHERMIC,0,0,0,0
CONVERGENCE
   30     .005      -.25
STEP     0       0.0      68.0
STEP     1      .025        347.600                              3
STEP     2      .025        627.200                              3
STEP     3      .025        906.800                              3
STEP     4      .025       1060.000                              3
STEP     5      .025       1150.000                              3
```

```
************************************************************


  FFFFF  I  RRRRR  EEEEE  SSSSS         TTTTT  33333
  F      I  R   R  E      S               T        3
  F      I  R   R  E      S               T       3
  F      I  R   R  E      S               T      3
  FFF    I  RRRRR  EEE    SSSSS  =====    T    3333
  F      I  RR     E          S           T        3
  F      I  R R    E          S           T        3
  F      I  R  R   E          S           T        3
  F      I  R   R  EEEEE  SSSSS           T    33333


    A THERMAL ANALYZER FOR THREE-DIMENSIONAL SYSTEMS,
    WITH TEMPERATURE-DEPENDENT THERMAL PROPERTIES,
    SUBJECTED TO A FIRE ENVIRONMENT


************************************************************


                 - - - TITLE OF RUN - - -

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **


************************************************************
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TABLE B.4 OUTPUT FOR SAMPLE PROBLEM TWO

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*********************************************************************

    FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **

      GEOMETRIC DESCRIPTION OF SYSTEM TO BE ANALYZED

*********************************************************************


 . . . . THERE ARE   220 NODAL POINTS . . . .


NODAL                             COORDINATES                    BOUNDARY
POINT          X                  Y                Z             CONDITION

   1          0.                0.               0.                  FLOW
   2          0.                0.                .0521              FLOW
   3          0.                0.                .1042              FLOW
   4          0.                0.                .1250              FLOW
   5           .1646            -.0261           0.                  FLOW
   6           .1646            -.0261            .0521              FLOW
   7           .1646            -.0261            .1042              FLOW
   8           .1646            -.0261            .1250              FLOW
   9           .1667            0.               0.                  FLOW
  10           .1667            0.                .0521              FLOW
  11           .1667            0.                .1042              FLOW
  12           .1667            0.                .1250              FLOW
  13           .1646             .0261           0.                  FLOW
  14           .1646             .0261            .0521              FLOW
  15           .1646             .0261            .1042              FLOW
  16           .1646             .0261            .1250              FLOW
  17           .2469            -.0391           0.                  FLOW
  18           .2469            -.0391            .0521              FLOW
  19           .2469            -.0391            .1042              FLOW
  20           .2469            -.0391            .1250              FLOW
  21           .2500            0.               0.                  FLOW
  22           .2500            0.                .0521              FLOW
  23           .2500            0.                .1042              FLOW
  24           .2500            0.                .1250              FLOW
  25           .2469             .0391           0.                  FLOW
  26           .2469             .0391            .0521              FLOW
  27           .2469             .0391            .1042              FLOW
  28           .2469             .0391            .1250              FLOW
  29           .3292            -.0522           0.                  FLOW
  30           .3292            -.0522            .0521              FLOW
  31           .3292            -.0522            .1042              FLOW
  32           .3292            -.0522            .1250              FLOW
  33           .3320            -.0302           0.                  FLOW
  34           .3320            -.0302            .0521              FLOW
  35           .3320            -.0302            .1042              FLOW
  36           .3320            -.0302            .1250              FLOW
  37           .3333            0.               0.                  FLOW
  38           .3333            0.                .0521              FLOW
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39                    .3333               0.                   .1042          FLOW
40                    .3333               0.                   .1250          FLOW
41                    .3292                .0522              0.              FLOW
42                    .3292                .0522               .0521          FLOW
43                    .3292                .0522               .1042          FLOW
44                    .3292                .0522               .1250          FLOW
45                    .4115               -.0652              0.              FLOW
46                    .4115               -.0652               .0521          FLOW
47                    .4115               -.0652               .1042          FLOW
48                    .4115               -.0652               .1250          FLOW
49                    .4149               -.0377              0.              FLOW
50                    .4149               -.0377               .0521          FLOW
51                    .4149               -.0377               .1042          FLOW
52                    .4149               -.0377               .1250          FLOW
53                    .4167               0.                  0.              FLOW
54                    .4167               0.                   .0521          FLOW
55                    .4167               0.                   .1042          FLOW
56                    .4167               0.                   .1250          FLOW
57                    .4115                .0652              0.              FLOW
58                    .4115                .0652               .0521          FLOW
59                    .4115                .0652               .1042          FLOW
60                    .4115                .0652               .1250          FLOW
61                    .4733               -.0749              0.              FLOW
62                    .4733               -.0749               .0521          FLOW
63                    .4733               -.0749               .1042          FLOW
64                    .4733               -.0749               .1250          FLOW
65                    .4772               -.0434              0.              FLOW
66                    .4772               -.0434               .0521          FLOW
67                    .4772               -.0434               .1042          FLOW
68                    .4772               -.0434               .1250          FLOW
69                    .4792               0.                  0.              FLOW
70                    .4792               0.                   .0521          FLOW
71                    .4792               0.                   .1042          FLOW
72                    .4792               0.                   .1250          FLOW
73                    .4733                .0749              0.              FLOW
74                    .4733                .0749               .0521          FLOW
75                    .4733                .0749               .1042          FLOW
76                    .4733                .0749               .1250          FLOW
77                    .5350               -.0848              0.              FLOW
78                    .5350               -.0848               .0521          FLOW
79                    .5350               -.0848               .1042          FLOW
80                    .5350               -.0848               .1250          FLOW
81                    .5394               -.0492              0.              FLOW
82                    .5394               -.0492               .0521          FLOW
83                    .5394               -.0492               .1042          FLOW
84                    .5394               -.0492               .1250          FLOW
85                    .5417               0.                  0.              FLOW
86                    .5417               0.                   .0521          FLOW
87                    .5417               0.                   .1042          FLOW
88                    .5417               0.                   .1250          FLOW
89                    .5350                .0848              0.              FLOW
90                    .5350                .0848               .0521          FLOW
91                    .5350                .0848               .1042          FLOW
92                    .5350                .0848               .1250          FLOW
93                    .5850               -.0927              0.              FLOW
94                    .5850               -.0927               .0521          FLOW
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 95        .5850        -.0927        .1042       FLOW
 96        .5850        -.0927        .1250       FLOW
 97        .5899        -.0537       0.           FLOW
 98        .5899        -.0537        .0521       FLOW
 99        .5899        -.0537        .1042       FLOW
100        .5899        -.0537        .1250       FLOW
101        .5923        0.           0.           FLOW
102        .5923        0.            .0521       FLOW
103        .5923        0.            .1042       FLOW
104        .5923        0.            .1250       FLOW
105        .5850         .0927       0.           FLOW
106        .5850         .0927        .0521       FLOW
107        .5850         .0927        .1042       FLOW
108        .5850         .0927        .1250       FLOW
109        .6262        -.0992       0.           FLOW
110        .6262        -.0992        .0521       FLOW
111        .6262        -.0992        .1042       FLOW
112        .6262        -.0992        .1250       FLOW
113        .6314        -.0575       0.           FLOW
114        .6314        -.0575        .0521       FLOW
115        .6314        -.0575        .1042       FLOW
116        .6314        -.0575        .1250       FLOW
117        .6340        0.           0.           FLOW
118        .6340        0.            .0521       FLOW
119        .6340        0.            .1042       FLOW
120        .6340        0.            .1250       FLOW
121        .6262         .0992       0.           FLOW
122        .6262         .0992        .0521       FLOW
123        .6262         .0992        .1042       FLOW
124        .6262         .0992        .1250       FLOW
125        .6673        -.1057       0.           FLOW
126        .6673        -.1057        .0521       FLOW
127        .6673        -.1057        .1042       FLOW
128        .6673        -.1057        .1250       FLOW
129        .6729        -.0613       0.           FLOW
130        .6729        -.0613        .0521       FLOW
131        .6729        -.0613        .1042       FLOW
132        .6729        -.0613        .1250       FLOW
133        .6757        0.           0.           FLOW
134        .6757        0.            .0521       FLOW
135        .6757        0.            .1042       FLOW
136        .6757        0.            .1250       FLOW
137        .6673         .1057       0.           FLOW
138        .6673         .1057        .0521       FLOW
139        .6673         .1057        .1042       FLOW
140        .6673         .1057        .1250       FLOW
141        .6996        -.1108       0.           FLOW
142        .6996        -.1108        .0521       FLOW
143        .6996        -.1108        .1042       FLOW
144        .6996        -.1108        .1250       FLOW
145        .7054        -.0642       0.           FLOW
146        .7054        -.0642        .0521       FLOW
147        .7054        -.0642        .1042       FLOW
148        .7054        -.0642        .1250       FLOW
149        .7083        0.           0.           FLOW
150        .7083        0.            .0521       FLOW
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151          .7083          0.               .1042          FLOW
152          .7083          0.               .1250          FLOW
153          .6996           .1108          0.              FLOW
154          .6996           .1108           .0521          FLOW
155          .6996           .1108           .1042          FLOW
156          .6996           .1108           .1250          FLOW
157          .7408          -.1173          0.              FLOW
158          .7408          -.1173           .0521          FLOW
159          .7408          -.1173           .1042          FLOW
160          .7408          -.1173           .1250          FLOW
161          .7469          -.0680          0.              FLOW
162          .7469          -.0680           .0521          FLOW
163          .7469          -.0680           .1042          FLOW
164          .7469          -.0680           .1250          FLOW
165          .7500          0.              0.              FLOW
166          .7500          0.               .0521          FLOW
167          .7500          0.               .1042          FLOW
168          .7500          0.               .1250          FLOW
169          .7408           .1173          0.              FLOW
170          .7408           .1173           .0521          FLOW
171          .7408           .1173           .1042          FLOW
172          .7408           .1173           .1250          FLOW
173          .7819          -.1238          0.              FLOW
174          .7819          -.1238           .0521          FLOW
175          .7819          -.1238           .1042          FLOW
176          .7819          -.1238           .1250          FLOW
177          .7884          -.0718          0.              FLOW
178          .7884          -.0718           .0521          FLOW
179          .7884          -.0718           .1042          FLOW
180          .7884          -.0718           .1250          FLOW
181          .7917          0.              0.              FLOW
182          .7917          0.               .0521          FLOW
183          .7917          0.               .1042          FLOW
184          .7917          0.               .1250          FLOW
185          .7819           .1238          0.              FLOW
186          .7819           .1238           .0521          FLOW
187          .7819           .1238           .1042          FLOW
188          .7819           .1238           .1250          FLOW
189          .8025          -.1271          0.              FLOW
190          .8025          -.1271           .0521          FLOW
191          .8025          -.1271           .1042          FLOW
192          .8025          -.1271           .1250          FLOW
193          .8092          -.0737          0.              FLOW
194          .8092          -.0737           .0521          FLOW
195          .8092          -.0737           .1042          FLOW
196          .8092          -.0737           .1250          FLOW
197          .8125          0.              0.              FLOW
198          .8125          0.               .0521          FLOW
199          .8125          0.               .1042          FLOW
200          .8125          0.               .1250          FLOW
201          .8025           .1271          0.              FLOW
202          .8025           .1271           .0521          FLOW
203          .8025           .1271           .1042          FLOW
204          .8025           .1271           .1250          FLOW
205          .8231          -.1303          0.              FLOW
206          .8231          -.1303           .0521          FLOW
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 207            .8231          -.1303            .1042          FLOW
 208            .8231          -.1303            .1250          FLOW
 209            .8299          -.0756          0.               FLOW
 210            .8299          -.0756            .0521          FLOW
 211            .8299          -.0756            .1042          FLOW
 212            .8299          -.0756            .1250          FLOW
 213            .8333          0.              0.               FLOW
 214            .8333          0.                .0521          FLOW
 215            .8333          0.                .1042          FLOW
 216            .8333          0.                .1250          FLOW
 217            .8231           .1303          0.               FLOW
 218            .8231           .1303            .0521          FLOW
 219            .8231           .1303            .1042          FLOW
 220            .8231           .1303            .1250          FLOW


 . . . . THERE ARE   120   3-D ELEMENTS . . . .


ELMT     I     J     K     L     M     N     O     P   MAT

   1     1     5     9     9     2     6    10    10     1
   2     2     6    10    10     3     7    11    11     1
   3     3     7    11    11     4     8    12    12     1
   4     1     9    13    13     2    10    14    14     1
   5     2    10    14    14     3    11    15    15     1
   6     3    11    15    15     4    12    16    16     1
   7     5    17    21     9     6    18    22    10     1
   8     6    18    22    10     7    19    23    11     1
   9     7    19    23    11     8    20    24    12     1
  10     9    21    25    13    10    22    26    14     1
  11    10    22    26    14    11    23    27    15     1
  12    11    23    27    15    12    24    28    16     1
  13    17    29    33    33    18    30    34    34     1
  14    18    30    34    34    19    31    35    35     1
  15    19    31    35    35    20    32    36    36     1
  16    17    33    37    21    18    34    38    22     1
  17    18    34    38    22    19    35    39    23     1
  18    19    35    39    23    20    36    40    24     1
  19    21    37    41    25    22    38    42    26     1
  20    22    38    42    26    23    39    43    27     1
  21    23    39    43    27    24    40    44    28     1
  22    29    45    49    33    30    46    50    34     1
  23    30    46    50    34    31    47    51    35     1
  24    31    47    51    35    32    48    52    36     1
  25    33    49    53    37    34    50    54    38     1
  26    34    50    54    38    35    51    55    39     1
  27    35    51    55    39    36    52    56    40     1
  28    37    53    57    41    38    54    58    42     1
  29    38    54    58    42    39    55    59    43     1
  30    39    55    59    43    40    56    60    44     1
  31    45    61    65    49    46    62    66    50     1
  32    46    62    66    50    47    63    67    51     1
  33    47    63    67    51    48    64    68    52     1
  34    49    65    69    53    50    66    70    54     1
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35    50    66    70    54    51    67    71    55     1
36    51    67    71    55    52    68    72    56     1
37    53    69    73    57    54    70    74    58     1
38    54    70    74    58    55    71    75    59     1
39    55    71    75    59    56    72    76    60     1
40    61    77    81    65    62    78    82    66     1
41    62    78    82    66    63    79    83    67     1
42    63    79    83    67    64    80    84    68     1
43    65    81    85    69    66    82    86    70     1
44    66    82    86    70    67    83    87    71     1
45    67    83    87    71    68    84    88    72     1
46    69    85    89    73    70    86    90    74     1
47    70    86    90    74    71    87    91    75     1
48    71    87    91    75    72    88    92    76     1
49    77    93    97    81    78    94    98    82     1
50    78    94    98    82    79    95    99    83     1
51    79    95    99    83    80    96   100    84     1
52    81    97   101    85    82    98   102    86     1
53    82    98   102    86    83    99   103    87     1
54    83    99   103    87    84   100   104    88     1
55    85   101   105    89    86   102   106    90     1
56    86   102   106    90    87   103   107    91     1
57    87   103   107    91    88   104   108    92     1
58    93   109   113    97    94   110   114    98     2
59    94   110   114    98    95   111   115    99     2
60    95   111   115    99    96   112   116   100     2
61    97   113   117   101    98   114   118   102     1
62    98   114   118   102    99   115   119   103     1
63    99   115   119   103   100   116   120   104     1
64   101   117   121   105   102   118   122   106     1
65   102   118   122   106   103   119   123   107     1
66   103   119   123   107   104   120   124   108     1
67   109   125   129   113   110   126   130   114     2
68   110   126   130   114   111   127   131   115     2
69   111   127   131   115   112   128   132   116     2
70   113   129   133   117   114   130   134   118     1
71   114   130   134   118   115   131   135   119     1
72   115   131   135   119   116   132   136   120     1
73   117   133   137   121   118   134   138   122     1
74   118   134   138   122   119   135   139   123     1
75   119   135   139   123   120   136   140   124     1
76   125   141   145   129   126   142   146   130     1
77   126   142   146   130   127   143   147   131     1
78   127   143   147   131   128   144   148   132     2
79   129   145   149   133   130   146   150   134     1
80   130   146   150   134   131   147   151   135     1
81   131   147   151   135   132   148   152   136     2
82   133   149   153   137   134   150   154   138     1
83   134   150   154   138   135   151   155   139     1
84   135   151   155   139   136   152   156   140     2
85   141   157   161   145   142   158   162   146     1
86   142   158   162   146   143   159   163   147     1
87   143   159   163   147   144   160   164   148     1
88   145   161   165   149   146   162   166   150     1
89   146   162   166   150   147   163   167   151     1
90   147   163   167   151   148   164   168   152     1
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 91  149  165  169  153  150  166  170  154       1
 92  150  166  170  154  151  167  171  155       1
 93  151  167  171  155  152  168  172  156       1
 94  157  173  177  161  158  174  178  162       1
 95  158  174  178  162  159  175  179  163       1
 96  159  175  179  163  160  176  180  164       1
 97  161  177  181  165  162  178  182  166       1
 98  162  178  182  166  163  179  183  167       1
 99  163  179  183  167  164  180  184  168       1
100  165  181  185  169  166  182  186  170       1
101  166  182  186  170  167  183  187  171       1
102  167  183  187  171  168  184  188  172       1
103  173  189  193  177  174  190  194  178       1
104  174  190  194  178  175  191  195  179       1
105  175  191  195  179  176  192  196  180       1
106  177  193  197  181  178  194  198  182       1
107  178  194  198  182  179  195  199  183       1
108  179  195  199  183  180  196  200  184       1
109  181  197  201  185  182  198  202  186       1
110  182  198  202  186  183  199  203  187       1
111  183  199  203  187  184  200  204  188       1
112  189  205  209  193  190  206  210  194       1
113  190  206  210  194  191  207  211  195       1
114  191  207  211  195  192  208  212  196       1
115  193  209  213  197  194  210  214  198       1
116  194  210  214  198  195  211  215  199       1
117  195  211  215  199  196  212  216  200       1
118  197  213  217  201  198  214  218  202       1
119  198  214  218  202  199  215  219  203       1
120  199  215  219  203  200  216  220  204       1


 • • • MAXIMUM BANDWIDTH IS    22 • • •
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   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **

   THERMAL PROPERTIES OF SYSTEM TO BE ANALYZED

   THERE ARE   2 DIFFERENT MATERIALS

**********************************************************



 . . . . MATERIAL NUMBER    1  . . . .


      . . . CONDUCTIVITY . . .

   NODE    TEMPERATURE        VALUE        SLOPE

      1          0.            .900
                                          0.
      2        390.0           .900
                                          -.313E-03
      3       1650.0           .506
                                          0.
      4       3000.0           .506


      . . . SPECIFIC HEAT . . .

 MATERIAL PARAMETER OF CONSTANT VALUE     .272


      . . . DENSITY . . .

 MATERIAL PARAMETER OF CONSTANT VALUE 150.000




 . . . . MATERIAL NUMBER    2  . . . .


      . . . CONDUCTIVITY . . .

   NODE    TEMPERATURE        VALUE        SLOPE

      1          0.          30.000
                                          -.918E-02
      2       1100.0         19.900
                                          0.
      3       3000.0         19.900
      . . . SPECIFIC HEAT . . .

    NODE     TEMPERATURE        VALUE       SLOPE

      1          0.              .107
                                              .493E-04
      2         750.0            .144
                                              .800E-04
      3        1100.0            .172
                                             0.
      4        3000.0            .172


      . . . DENSITY . . .

 MATERIAL PARAMETER OF CONSTANT VALUE 480.000
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    FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **

    NON-LINEAR FIRE BOUNDARY CONDITION

*****************************************************************


Q=A*(TF-TS)**N+SB*V*(AE*EF*(TF+TSHIFT)**4-ES*(TS+TSHIFT)**4)


WHERE
     TF - PSUEDO FIRE TEMPERATURE
     TS - SURFACE TEMPERATURE
     SB - STEFAN BOLZTMANN CONSTANT =     .1700E-08
     TSHIFT - SHIFT TO ABSOLUTE TEMPERATURE SCALE =     460.0
AND


MAT  CONVECT  CONVECT      VIEW  ABSORBT      FIRE  SURFACE
NUM   FACTOR    POWER    FACTOR             EMISSIV  EMISSIV
         (A)      (N)       (V)      (AE)     (EF)      (ES)

  1     .270    1.250     1.000      .900     .900      .900



 . . . THERE ARE   9 3-D SURFACE ELEMENTS EXPOSED TO FIRE . .


        DESCRIPTION OF SURFACE DIRECTLY EXPOSED TO FIRE

FIREBC   NODE     NODE     NODE     NODE      MAT    FIRE       AREA
SURFACE     I        J        K        L     TYPE    TYPE

     1    205      209      210      206        1       1       .003
     2    206      210      211      207        1       1       .003
     3    207      211      212      208        1       1       .001
     4    209      213      214      210        1       1       .004
     5    210      214      215      211        1       1       .004
     6    211      215      216      212        1       1       .002
     7    213      217      218      214        1       1       .007
     8    214      218      219      215        1       1       .007
     9    215      219      220      216        1       1       .003
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    FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **

    INFORMATION RELEVANT TO THE ANALYSIS PROCEDURE

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 . . . . CONVERGENCE CRITERIA . . . .


 CONVERGENCE CRITERIA FOR BOUNDARY CONDITIONS

    PERMISSIBLE ERROR =     .00500
    MAXIMUM NUMBER OF ITERATIONS =   30     BETA =     -.2500



 . . . . STORAGE REQUIREMENT FOR BLANK COMMON . . . .

    SIZE BLANK COMMON =        8923 (DECIMAL)
                      =     0021333 (OCTAL)
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   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **

INITIAL SEQUENCE NUMBER IS    0 AND INITIAL TIME IS     0.

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----------- NODAL POINT TEMPERATURES --------------


   N      TEMP.       N      TEMP.       N      TEMP.       N      TEMP.
   1      68.00       2      68.00       3      68.00       4      68.00
   5      68.00       6      68.00       7      68.00       8      68.00
   9      68.00      10      68.00      11      68.00      12      68.00
  13      68.00      14      68.00      15      68.00      16      68.00
  17      68.00      18      68.00      19      68.00      20      68.00
  21      68.00      22      68.00      23      68.00      24      68.00
  25      68.00      26      68.00      27      68.00      28      68.00
  29      68.00      30      68.00      31      68.00      32      68.00
  33      68.00      34      68.00      35      68.00      36      68.00
  37      68.00      38      68.00      39      68.00      40      68.00
  41      68.00      42      68.00      43      68.00      44      68.00
  45      68.00      46      68.00      47      68.00      48      68.00
  49      68.00      50      68.00      51      68.00      52      68.00
  53      68.00      54      68.00      55      68.00      56      68.00
  57      68.00      58      68.00      59      68.00      60      68.00
  61      68.00      62      68.00      63      68.00      64      68.00
  65      68.00      66      68.00      67      68.00      68      68.00
  69      68.00      70      68.00      71      68.00      72      68.00
  73      68.00      74      68.00      75      68.00      76      68.00
  77      68.00      78      68.00      79      68.00      80      68.00
  81      68.00      82      68.00      83      68.00      84      68.00
  85      68.00      86      68.00      87      68.00      88      68.00
  89      68.00      90      68.00      91      68.00      92      68.00
  93      68.00      94      68.00      95      68.00      96      68.00
  97      68.00      98      68.00      99      68.00     100      68.00
 101      68.00     102      68.00     103      68.00     104      68.00
 105      68.00     106      68.00     107      68.00     108      68.00
 109      68.00     110      68.00     111      68.00     112      68.00
 113      68.00     114      68.00     115      68.00     116      68.00
 117      68.00     118      68.00     119      68.00     120      68.00
 121      68.00     122      68.00     123      68.00     124      68.00
 125      68.00     126      68.00     127      68.00     128      68.00
 129      68.00     130      68.00     131      68.00     132      68.00
 133      68.00     134      68.00     135      68.00     136      68.00
 137      68.00     138      68.00     139      68.00     140      68.00
 141      68.00     142      68.00     143      68.00     144      68.00
 145      68.00     146      68.00     147      68.00     148      68.00
 149      68.00     150      68.00     151      68.00     152      68.00
 153      68.00     154      68.00     155      68.00     156      68.00
 157      68.00     158      68.00     159      68.00     160      68.00
```

```
161     68.00     162     68.00     163     68.00     164     68.00
165     68.00     166     68.00     167     68.00     168     68.00
169     68.00     170     68.00     171     68.00     172     68.00
173     68.00     174     68.00     175     68.00     176     68.00
177     68.00     178     68.00     179     68.00     180     68.00
181     68.00     182     68.00     183     68.00     184     68.00
185     68.00     186     68.00     187     68.00     188     68.00
189     68.00     190     68.00     191     68.00     192     68.00
193     68.00     194     68.00     195     68.00     196     68.00
197     68.00     198     68.00     199     68.00     200     68.00
201     68.00     202     68.00     203     68.00     204     68.00
205     68.00     206     68.00     207     68.00     208     68.00
209     68.00     210     68.00     211     68.00     212     68.00
213     68.00     214     68.00     215     68.00     216     68.00
217     68.00     218     68.00     219     68.00     220     68.00
```

```
*************************************************************

   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **

 TIME STEP NUMBER     1 - TIME     .025 - TIME STEP     .025

*************************************************************

    NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS   -0

    FIRE BOUNDARY CONDITION
     FIRE(1) =     347.600
     FIRE(2) =       -0.
     FIRE(3) =       -0.
     FIRE(4) =       -0.


------------ NODAL POINT TEMPERATURES ---------------


     N     TEMP.       N     TEMP.       N     TEMP.       N     TEMP.
     1     68.00       2     68.00       3     68.00       4     68.00
     5     68.00       6     68.00       7     68.00       8     68.00
     9     68.00      10     68.00      11     68.00      12     68.00
    13     68.00      14     68.00      15     68.00      16     68.00
    17     68.00      18     68.00      19     68.00      20     68.00
    21     68.00      22     68.00      23     68.00      24     68.00
    25     68.00      26     68.00      27     68.00      28     68.00
    29     68.00      30     68.00      31     68.00      32     68.00
    33     68.00      34     68.00      35     68.00      36     68.00
    37     68.00      38     68.00      39     68.00      40     68.00
    41     68.00      42     68.00      43     68.00      44     68.00
    45     68.00      46     68.00      47     68.00      48     68.00
    49     68.00      50     68.00      51     68.00      52     68.00
    53     68.00      54     68.00      55     68.00      56     68.00
    57     68.00      58     68.00      59     68.00      60     68.00
    61     68.00      62     68.00      63     68.00      64     68.00
    65     68.00      66     68.00      67     68.00      68     68.00
    69     68.00      70     68.00      71     68.00      72     68.00
    73     68.00      74     68.00      75     68.00      76     68.00
    77     68.00      78     68.00      79     68.00      80     68.00
    81     68.00      82     68.00      83     68.00      84     68.00
    85     68.00      86     68.00      87     68.00      88     68.00
    89     68.00      90     68.00      91     68.00      92     68.00
    93     68.02      94     68.02      95     68.02      96     68.02
    97     68.02      98     68.02      99     68.02     100     68.02
   101     68.00     102     68.00     103     68.00     104     68.00
   105     68.00     106     68.00     107     68.00     108     68.00
   109     68.02     110     68.02     111     68.03     112     68.03
   113     68.02     114     68.02     115     68.03     116     68.03
   117     68.01     118     68.01     119     68.01     120     68.01
   121     68.01     122     68.01     123     68.01     124     68.01
   125     68.02     126     68.02     127     68.04     128     68.04
```

```
  129     68.03   130     68.03   131     68.04   132     68.05
  133     68.04   134     68.03   135     68.07   136     68.07
  137     68.04   138     68.03   139     68.07   140     68.08
  141     68.13   142     68.13   143     68.07   144     68.06
  145     68.13   146     68.13   147     68.07   148     68.06
  149     68.13   150     68.13   151     68.09   152     68.08
  153     68.13   154     68.14   155     68.09   156     68.09
  157     68.62   158     68.61   159     68.61   160     68.61
  161     68.62   162     68.61   163     68.61   164     68.61
  165     68.62   166     68.62   167     68.61   168     68.61
  169     68.62   170     68.62   171     68.62   172     68.62
  173     70.96   174     70.96   175     70.96   176     70.96
  177     70.97   178     70.97   179     70.97   180     70.97
  181     70.98   182     70.98   183     70.98   184     70.98
  185     70.98   186     70.98   187     70.98   188     70.98
  189     75.49   190     75.49   191     75.49   192     75.49
  193     75.51   194     75.51   195     75.51   196     75.51
  197     75.52   198     75.52   199     75.52   200     75.52
  201     75.52   202     75.52   203     75.52   204     75.52
  205     85.73   206     85.73   207     85.73   208     85.73
  209     85.74   210     85.74   211     85.74   212     85.74
  213     85.74   214     85.74   215     85.74   216     85.74
  217     85.75   218     85.75   219     85.75   220     85.75


-------------- TEMPERATURE OF 3-D ELEMENTS ------------


    N     TEMP.     N     TEMP.     N     TEMP.     N     TEMP.
    1     68.00     2     68.00     3     68.00     4     68.00
    5     68.00     6     68.00     7     68.00     8     68.00
    9     68.00    10     68.00    11     68.00    12     68.00
   13     68.00    14     68.00    15     68.00    16     68.00
   17     68.00    18     68.00    19     68.00    20     68.00
   21     68.00    22     68.00    23     68.00    24     68.00
   25     68.00    26     68.00    27     68.00    28     68.00
   29     68.00    30     68.00    31     68.00    32     68.00
   33     68.00    34     68.00    35     68.00    36     68.00
   37     68.00    38     68.00    39     68.00    40     68.00
   41     68.00    42     68.00    43     68.00    44     68.00
   45     68.00    46     68.00    47     68.00    48     68.00
   49     68.01    50     68.01    51     68.01    52     68.01
   53     68.01    54     68.01    55     68.00    56     68.00
   57     68.00    58     68.02    59     68.02    60     68.02
   61     68.01    62     68.01    63     68.02    64     68.01
   65     68.01    66     68.01    67     68.02    68     68.03
   69     68.03    70     68.02    71     68.03    72     68.04
   73     68.02    74     68.03    75     68.04    76     68.08
   77     68.07    78     68.05    79     68.08    80     68.07
   81     68.07    82     68.09    83     68.08    84     68.08
   85     68.37    86     68.36    87     68.34    88     68.38
   89     68.36    90     68.34    91     68.38    92     68.36
   93     68.35    94     69.79    95     69.79    96     69.79
   97     69.80    98     69.79    99     69.79   100     69.80
  101     69.80   102     69.80   103     73.23   104     73.23
  105     73.23   106     73.24   107     73.24   108     73.24
```

```
109     73.25    110     73.25    111     73.25    112     80.62
113     80.62    114     80.62    115     80.63    116     80.63
117     80.63    118     80.63    119     80.63    120     80.63

 0 SYSTEM ITERATIONS WERE PERFORMED
 3 B. C. ITERATIONS WERE PERFORMED
```

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   FIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL

 ** CIRCULAR COLUMN WITH 1/2 INCH SPIRAL - 3-D ANALYSIS **

 TIME STEP NUMBER     2 - TIME     .050 - TIME STEP     .025

************************************************************

    NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS   -0

    FIRE BOUNDARY CONDITION
     FIRE(1) =    627.200
     FIRE(2) =      -0.
     FIRE(3) =      -0.
     FIRE(4) =      -0.


------------ NODAL POINT TEMPERATURES ---------------


     N     TEMP.       N     TEMP.       N     TEMP.       N     TEMP.
     1     68.00       2     68.00       3     68.00       4     68.00
     5     68.00       6     68.00       7     68.00       8     68.00
     9     68.00      10     68.00      11     68.00      12     68.00
    13     68.00      14     68.00      15     68.00      16     68.00
    17     68.00      18     68.00      19     68.00      20     68.00
    21     68.00      22     68.00      23     68.00      24     68.00
    25     68.00      26     68.00      27     68.00      28     68.00
    29     68.00      30     68.00      31     68.00      32     68.00
    33     68.00      34     68.00      35     68.00      36     68.00
    37     68.00      38     68.00      39     68.00      40     68.00
    41     68.00      42     68.00      43     68.00      44     68.00
    45     68.00      46     68.00      47     68.00      48     68.00
    49     68.00      50     68.00      51     68.00      52     68.00
    53     68.00      54     68.00      55     68.00      56     68.00
    57     68.00      58     68.00      59     68.00      60     68.00
    61     68.00      62     68.00      63     68.00      64     68.00
    65     68.00      66     68.00      67     68.00      68     68.00
    69     68.00      70     68.00      71     68.00      72     68.00
    73     68.00      74     68.00      75     68.00      76     68.00
    77     68.02      78     68.02      79     68.02      80     68.02
    81     68.01      82     68.01      83     68.02      84     68.02
    85     68.01      86     68.01      87     68.01      88     68.01
    89     68.00      90     68.00      91     68.00      92     68.00
    93     68.12      94     68.13      95     68.14      96     68.14
    97     68.11      98     68.12      99     68.13     100     68.13
   101     68.02     102     68.02     103     68.02     104     68.02
   105     68.01     106     68.02     107     68.02     108     68.02
   109     68.14     110     68.15     111     68.17     112     68.17
   113     68.13     114     68.14     115     68.16     116     68.16
   117     68.06     118     68.07     119     68.08     120     68.09
   121     68.05     122     68.07     123     68.09     124     68.09
   125     68.15     126     68.16     127     68.23     128     68.25
```

```
  129     68.17    130     68.17    131     68.27    132     68.30
  133     68.24    134     68.22    135     68.42    136     68.44
  137     68.24    138     68.22    139     68.44    140     68.47
  141     68.78    142     68.78    143     68.39    144     68.35
  145     68.78    146     68.79    147     68.42    148     68.38
  149     68.80    150     68.80    151     68.51    152     68.48
  153     68.80    154     68.81    155     68.55    156     68.52
  157     71.30    158     71.28    159     71.24    160     71.23
  161     71.30    162     71.28    163     71.25    164     71.24
  165     71.32    166     71.30    167     71.27    168     71.26
  169     71.32    170     71.31    171     71.29    172     71.28
  173     81.86    174     81.85    175     81.85    176     81.85
  177     81.88    178     81.87    179     81.87    180     81.87
  181     81.93    182     81.93    183     81.92    184     81.92
  185     81.93    186     81.93    187     81.92    188     81.92
  189     99.46    190     99.46    191     99.45    192     99.45
  193     99.54    194     99.54    195     99.54    196     99.54
  197     99.55    198     99.55    199     99.55    200     99.55
  201     99.55    202     99.55    203     99.54    204     99.54
  205    135.23    206    135.23    207    135.22    208    135.22
  209    135.28    210    135.28    211    135.28    212    135.28
  213    135.27    214    135.27    215    135.27    216    135.27
  217    135.28    218    135.28    219    135.28    220    135.28


-------------- TEMPERATURE OF 3-D ELEMENTS -------------


    N     TEMP.      N     TEMP.      N     TEMP.      N     TEMP.
    1     68.00      2     68.00      3     68.00      4     68.00
    5     68.00      6     68.00      7     68.00      8     68.00
    9     68.00     10     68.00     11     68.00     12     68.00
   13     68.00     14     68.00     15     68.00     16     68.00
   17     68.00     18     68.00     19     68.00     20     68.00
   21     68.00     22     68.00     23     68.00     24     68.00
   25     68.00     26     68.00     27     68.00     28     68.00
   29     68.00     30     68.00     31     68.00     32     68.00
   33     68.00     34     68.00     35     68.00     36     68.00
   37     68.00     38     68.00     39     68.00     40     68.01
   41     68.01     42     68.01     43     68.01     44     68.01
   45     68.01     46     68.00     47     68.00     48     68.00
   49     68.07     50     68.07     51     68.08     52     68.04
   53     68.04     54     68.04     55     68.01     56     68.01
   57     68.01     58     68.13     59     68.14     60     68.15
   61     68.08     62     68.09     63     68.10     64     68.04
   65     68.05     66     68.05     67     68.15     68     68.18
   69     68.22     70     68.15     71     68.19     72     68.24
   73     68.15     74     68.20     75     68.27     76     68.47
   77     68.40     78     68.32     79     68.50     80     68.45
   81     68.40     82     68.52     83     68.50     84     68.48
   85     70.03     86     69.93     87     69.81     88     70.04
   89     69.95     90     69.85     91     70.06     92     69.98
   93     69.89     94     76.58     95     76.56     96     76.55
   97     76.60     98     76.59     99     76.58    100     76.62
  101     76.61    102     76.60    103     90.68    104     90.68
  105     90.68    106     90.72    107     90.72    108     90.72
  109     90.74   110     90.74   111     90.73   112    117.37
  113    117.37   114    117.37   115    117.41   116    117.41
  117    117.41   118    117.41   119    117.41   120    117.41


   0 SYSTEM ITERATIONS WERE PERFORMED
   3 B. C. ITERATIONS WERE PERFORMED



PROBLEM COMPLETED
```

APPENDIX C

LISTING OF COMPUTER PROGRAM FIRES-T3

The following listing is the operational version of FIRES-T3 as of September 1977. Although the program has been tested, no warranty is made regarding its accuracy or reliability, and no responsibility is assumed in this respect.

```
      PROGRAM FIREST3(INPUT,OUTPUT,PUNCH,TAPE1=INPUT,TAPE2=OUTPUT,TAPE3=
     1PUNCH,TAPE6)
C
C
C     ******************************************************************
C                                                                      *
C      *FIRES-T3* IS A PROGRAM FOR TRANSIENT, NONLINEAR, ONE-, TWO-,   *
C      AND 3-DIMENSIONAL HEAT FLOW PROBLEMS IN WHICH THERMAL PROPER-   *
C      TIES OF THE MATERIAL CAN BE FUNCTIONS OF TEMPERATURE.  A FIRE   *
C      ENVIRONMENT CAN BE SIMULATED WITH OPTIONAL LINEAR AND NONLINEAR *
C      BOUNDARY CONDITIONS.  THE ANALYTICAL APPROACH USED IS THAT OF A *
C      FINITE ELEMENT TECHNIQUE COUPLED WITH A TIME STEP INTEGRATION.  *
C      THE PROGRAM IS DYNAMICALLY DIMENSIONED TO ALLOW FOR MINIMUM     *
C      CENTRAL MEMORY STORAGE.                                         *
C                                                                      *
C          ORIGINAL VERSION           AUGUST 1977                      *
C                                                                      *
C          PROGRAMMED BY R. IDING AND B. BRESLER                       *
C                                                                      *
C          UNIVERSITY OF CALIFORNIA     BERKELEY                       *
C                                                                      *
C     ******************************************************************
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      COMMON /EXOTH/ NINT1D,NINT2D,NINT3D,NINT,NCINT
      COMMON C(10000)
C
C
      NIN=1
      NOUT=2
      NPUNCH=3
      NALLOW=10000
C
C     INPUT TITLE
C
   10 READ (NIN,100) ITITLE
C
C     INPUT OF PROBLEM DESCRIPTION DONE ON BASIS OF ALPHA-NUMERIC
C     CONTROL CARDS IN WHICH THE FIRST LETTER OF THE CONTROL
C     WORD IS CHECKED FOR PROPER INPUT SEQUENCE
C
C     INPUT CONTROL CARD * NODES *
C
      READ (NIN,160) IREAD
      IF (IREAD(1).EQ.55B) STOP
      IF (IREAD(1).NE.16B) GO TO 90
      N=1
C
C     OUTPUT TITLE PAGE
C
      WRITE (NOUT,110)
      WRITE (NOUT,120)
      WRITE (NOUT,130)
      WRITE (NOUT,140)
      WRITE (NOUT,120)
      WRITE (NOUT,150) ITITLE
      WRITE (NOUT,120)
C
C     INPUT OF NODAL DATA
C
```

```
C        NUMNP - NUMBER OF NODAL POINTS
C        NTBC - NUMBER OF KNOWN TEMPERATURE BOUNDARY CONDITIONS
C        X(I)=C(N1) - X COORDINATE OF NODAL POINT
C        Y(I)=C(N2) - Y COORDINATE OF NODAL POINT
C        Z(I)=C(N3) - Z COORDINATE OF NODAL POINT
C        KODE(I)=C(ND0) - INDICATES TYPE OF BOUNDARY CONDITION
C                          FLOW - HEAT FLOW IS KNOWN
C                          TEMP - TEMPERATURE IS KNOWN
C        DUMI(I)=C(NDI) - DUMMY VARIABLES REQUIRED IN CALCULATION
C                          I VARIES FROM 1 TO 5
C
      NUMNP=NUMBER(N)
      IF (NUMNP.LE.0) GO TO 90
      NTBC=NUMBER(N)
      IF (NTBC.GT.NUMNP) GO TO 90
      N1=1
      N2=N1+NUMNP
      N3=N2+NUMNP
      ND0=N3+NUMNP
      ND1=ND0+NUMNP
      ND2=ND1+NUMNP
      ND3=ND2+NUMNP
      ND4=ND3+NUMNP
      ND5=ND4+NUMNP
      N4=ND5+NUMNP
C
      CALL NODE (C(N1),C(N2),C(N3),C(ND0),C(ND1),NTBC)
C
C     INPUT CONROL CARD * ELEMENTS *
C
      READ (NIN,160) IREAD
      IF (IREAD(1).NE.5B) GO TO 90
      N=1
C
C     INPUT OF ELEMENT DATA
C
C        NEL1D - NUMBER OF 1-D ELEMENTS
C        NEL2D - NUMBER OF 2-D ELEMENTS
C        NEL3D - NUMBER OF 3-D ELEMENTS
C        NUMEL - TOTAL NUMBER OF ELEMENTS
C        MBAND - MAXIMUM BANDWIDTH OF CONDUCTIVITY MATRIX
C        LM(I)=C(N4) - ELEMENT NODAL POINT CONFIGURATION ARRAY
C        MMTYPE(I)=C(N5) - MATERIAL TYPE
C        BAREA(I)=C(N6) - BAR AREA ( FOR 1-D ELEMENTS )
C        THICK(I)=C(N7) - ELEMENT THICKNESS ( FOR 2-D ELEMENTS )
C        VOLUME(I)=C(NV) - ELEMENT VOLUME ( FOR 3-D ELEMENTS )
C
      NEL1D=NUMBER(N)
      NEL2D=NUMBER(N)
      NEL3D=NUMBER(N)
      NUMEL=NEL1D+NEL2D+NEL3D
      IF (NUMEL.LE.0) GO TO 90
      N5=N4+2*NEL1D+4*NEL2D+8*NEL3D
      N6=N5+NUMEL
      N7=N6+NEL1D
      NV=N7+NEL2D
      N8=NV+NEL3D
C
      CALL ELEMENT (C(N1),C(N2),C(N3),C(N4),C(N5),C(N6),C(N7),C(NV))
C
C     INPUT CONTROL CARD * MATERIALS *
C
```

```
      READ (NIN,160) IREAD
      IF (IREAD(1).NE.15H) GO TO 90
      N=1
C
C     INPUT OF THERMAL PROPERTIES FOR DIFFERENT MATERIALS
C
C        NMAT - NUMBER OF DIFFERENT MATERIALS
C        MATL(I)=C(N8) - CONTROL DATA REQUIRED FOR CALCULATION OF
C                        THERMAL PROPERTIES
C        XYS(I)=C(N9) - FUNCTION VALUES FOR THERMAL PROPERTIES
C                       CONTAINS  X COORDINATE - TEMPERATURE
C                                 Y COORDINATE - FUNCTION VALUE
C                                 S - SLOPE OF LINES CONNECTING X,Y PAIR
C
      NMAT=NUMBER(N)
      IF (NMAT.EQ.0) GO TO 90
      N9=N8+6*NMAT
C
      CALL MATRIAL (C(N8),C(N9),N)
      N10=N9+N
C
C     INPUT CONTROL CARD * FIRE *
C
      READ (NIN,160) IREAD
      N=1
      IF (IREAD(1).NE.6H) GO TO 90
C
C     INPUT OF FIRE BOUNDARY CONDITION DATA
C
C        NFBC1D - NUMBER OF FIRE B.C. SURFACE NODES (FOR 1-D ELEMENTS)
C        NFBC2D - NUMBER OF FIRE B.C. SURFACE ELMTS (FOR 2-D ELEMENTS)
C        NFBC3D - NUMBER OF FIRE B.C. SURFACE ELMTS (FOR 3-D ELEMENTS)
C          ( THESE ARE MAXIMUMS IN ORDER TO ALLOT STORAGE )
C        NBCMAT - NUMBER OF DIFFERENT MATERIALS FOR FIRE B.C.
C        NBCTYP - TYPE OF FIRE B.C.
C        MAT(I)=C(N10)  - CONTROL DATA REQUIRED FOR CALCULATION OF FIRE
C                         BOUNDARY CONDITION PROPERTIES
C        FXYS(I)=C(N11) - CONTAINS FUNCTIONS OF FIRE B.C. PROPERTIES
C                         STRUCTURED SAME AS XYS
C
      NFBC1D=NUMBER(N)
      NFBC2D=NUMBER(N)
      NFBC3D=NUMBER(N)
      NUMFBC=NFBC1D+NFBC2D+NFBC3D
      IF (NUMFBC.EQ.0) GO TO 40
      NBCMAT=NUMBER(N)
      READ (NIN,160) IREAD
      IF (IREAD(1).NE.14H) GO TO 20
C
C     LINEAR FIRE BOUNDARY CONDITION
C
C        Q = H(T)*(TF-TS)   WHERE
C                           H(T) - SURFACE HEAT TRANSFER COEFFICENT
C                           TF  - PSUEDO-FIRE TEMPERATURE (INPUT DATA)
C                           TS - SURFACE TEMPERATURE OF SYSTEM
C                           T=(TF+TS)/2
C
      NBCTYP=10HLINEAR BC
      N11=N10+2*NBCMAT
      GO TO 30
C
   20 IF (IREAD(1).NE.1[illegible]) GO TO 50
```

```
C
C     NON-LINEAR FIRE BOUNDARY CONDITION
C
C        Q = A*(TF-TS)**N + V*SB*(AB*EF*ATF**4-ES*ATS**4)
C
C        WHERE  A - CONVECTION FACTOR
C               N - POWER OF CONVECTION TERM
C               V - VIEW FACTOR FOR RADIATION TERM
C               SB - STEFANN BOLTZMANN CONSTANT
C               AB - ABSORBTION FACTOR OF FIRE
C               EF - EMISSIVITY OF FIRE
C               ES - EMISSIVITY OF SURFACE
C               ATF - ABSOLUTE TEMPERATURE OF PSUEDO FIRE
C               ATS - ABSOLUTE TEMPERATURE OF SURFACE OF SYSTEM
C
      NBCTYP=10HNON-LIN BC
      N11=N10+NBCMAT
C
   30 CONTINUE
C
      CALL FIREMAT (C(N10),C(N11),N)
      N12=N11+N
C
C     INPUT OF GEOMETRIC DESCRIPTION OF FIRE BOUNDARY
C
C         LI(1)=C(N12) - FIRST  NODE THAT BOUNDS FIRE SURFACE ELEM
C                        ( 1-D, 2-D, AND 3-D ELEMENTS )
C         LJ(1)=C(N13) - SECOND NODE THAT BOUNDS FIRE SURFACE ELEM
C                        ( 2-D AND 3-D ELEMENTS ONLY )
C         LK(1)=C(N14) - THIRD  NODE THAT BOUNDS FIRE SURFACE ELEM
C                        ( 3-D ELEMENTS ONLY )
C         LL(1)=C(N15) - FOURTH NODE THAT BOUNDS FIRE SURFACE ELEM
C                        ( 3-D ELEMENTS ONLY )
C        LMAT(1)=C(N16) - FIRE BOUNDARY CONDITION TYPE (MATERIAL)
C        LFIRE(1)=C(N17) - NUMBER OF FIRE ACTIVE ON SURFACE I, I-J,
C                          OR I-J-K-L
C        AIJKL(1)=C(N18) - AREA OF SURFACE I, I-J, OR I-J-K-L
C        LELEM(1)=C(N19) - NUMBER OF FINITE ELEMENT ADJACENT TO THE
C                          FIRE SURFACE ( 1-D AND 2-D ONLY )
C
      N13=N12+NUMFBC
      N14=N13+NFBC2D+NFBC3D
      N15=N14+NFBC3D
      N16=N15+NFBC3D
      N17=N16+NUMFBC
      N18=N17+NUMFBC
      N19=N18+NUMFBC
      N20=N19+NFBC1D+NFBC2D
C
      CALL FIREBC (C(N1),C(N2),C(N3),C(ND0),C(N6),C(N7),C(N12),C(N13),C(
     1N14),C(N15),C(N16),C(N17),C(N18),C(N19))
      GO TO 50
C
   40 CONTINUE
C
C     WHEN NO FIRE B.C. IS SPECIFIED, INITIALIZE N11 - N20
C
      N11=N10
      N12=N10
      N13=N10
      N14=N10
      N15=N10
      N16=N10
      N17=N10
      N18=N10
      N19=N10
      N20=N10
C
C     INPUT CONTROL CARD * EXOTHERMIC *
C
   50 READ (NIN,160) IREAD
      IF (IREAD(1).NE.58) GO TO 90
      N=1
C
C     INPUT OF DATA DESCRIBING INTERNAL EXOTHERMIC HEAT GENERATION
C
C        NINT1D - NUMBER OF 1-D ELEMENTS WITH INTERNAL HEAT GENERATION
C        NINT2D - NUMBER OF 2-D ELEMENTS WITH INTERNAL HEAT GENERATION
C        NINT3D - NUMBER OF 3-D ELEMENTS WITH INTERNAL HEAT GENERATION
C        NINT - TOTAL NUMBER OF ELEMENTS WITH HEAT GENERATION
C        NQINT - NUMBER OF DIFFERENT HEATING CURVES
C        IEXO(1)=C(N20) - CONTROL DATA FOR HEATING CURVES
C        EXYS(1)=C(N21) - CONTAINS FUNCTION VALUES FOR HEATING CURVE
C                         X-COORDINATE - TIME
C                         Y-COORDINATE - HEAT RATE
C                         S - SLOPE OF LINES CONNECTING X,Y PAIRS
C        IEL(1)=C(N22) - ELEMENT NUMBER OF EACH ELEMENT UNDERGOING
C                        EXOTHERMIC HEATING
C        IMAT(1)=C(N23) - HEATING CURVE OF EACH ELEMENT UNDERGOING
C                         EXOTHERMIC HEATING
C        VEL(1)=C(N24) - VOLUME OF EACH ELEMENT
C
      NINT1D=NUMBER(N)
      NINT2D=NUMBER(N)
      NINT3D=NUMBER(N)
      NINT=NINT1D+NINT2D+NINT3D
      IF (NINT.NE.0) GO TO 60
      N21=N20
      N22=N20
      N23=N20
      N24=N20
      N25=N20
      GO TO 70
   60 NQINT=NUMBER(N)
      N21=N20+NQINT*3
      CALL EXOFUN (C(N20),C(N21),N)
      N22=N21+N
      N23=N22+NINT
      N24=N23+NINT
      N25=N24+NINT
      CALL EXOELS (C(N1),C(N2),C(N3),C(N4),C(N5),C(N7),C(NV),C(N22),C(N2
     13),C(N24))
C
C     ESTABLISH ADDITIONAL DYNAMICALLY DIMENSIONED VARIABLES REQUIRED
C     IN THE HEAT FLOW ANALYSIS
C
C        Q(1)=C(N25) - FLOW VECTOR
C        T(1)=C(N26) - TEMPERATURE VECTOR
C        B(1)=C(N27) - HEAT LOAD (FLOW) VECTOR USED IN ANALYSIS
C        AT(1)=C(N28) - ELEMENT TEMPERATURES
C        A(1,1)=C(N29) - MODIFIED CONDUCTIVITY MATRIX
C        NTOTAL - TOTAL AMOUNT OF STORAGE REQUIRED FOR BLANK COMMON
C
   70 N26=N25+NUMNP
```

```
      N27=N26+NUMNP
      N28=N27+NUMNP
      N29=N28+NUMEL
      NTOTAL=N29+NUMNP*MBAND
      IF (NTOTAL.LE.NALLOW) GO TO 80
      WRITE (NOUT,180) NTOTAL
      STOP
C
C     INPUT CONTROL CARD * CONVERGENCE *
C
   80 READ (NIN,160) IREAD
      IF (IREAD(1).NE.38) GO TO 90
C
C     INPUT CONVERGENCE CONTROL DATA FOR ITERATIVE PROCESS
C
      CALL CONVERG (NTOTAL)
C
C     TRANSFER CONTROL OF PROGRAM TO HEAT FLOW ANALYSIS ROUTINE
C     IN ORDER TO CARRY OUT STEP-BY-STEP TIME INTEGRATION
C
      CALL HEATFLO (C(N1),C(N2),C(N3),C(ND0),C(ND1),C(ND2),C(ND3),C(ND4)
     1,C(ND5),C(N4),C(N5),C(N6),C(N7),C(N8),C(N9),C(N10),C(N11),C(N12),C
     2(N13),C(N14),C(N15),C(N16),C(N17),C(N18),C(N19),C(N20),C(N21),C(N2
     32),C(N23),C(N24),C(N25),C(N26),C(N27),C(N28),C(N29),C(NV),NUMNP,NU
     4MFBC)
      GO TO 10
C
   90 CONTINUE
C
C     ERROR WAS DETECTED IN CONTROL WORD OR CONTROL VARIABLE
C     HAS IMPROPER VALUE AND PROGRAM IS TERMINATED
C
      WRITE (NOUT,170) IREAD
      STOP
C
C
C
  100 FORMAT (6A10)
  110 FORMAT (1H6,13(/))
  120 FORMAT (61H ******************************************************
     1******)
  130 FORMAT (///,5X,50HFFFFF   I  RRRRR  EEEEE  SSSSS          TTTTT  333
     133/5X,50HF        I  R   R  E      S              T       3 /5X,50H
     2F        I  R   R  E      S              T       3  /5X,50HF       I
     3 R   R  E      S              T       3   /5X,50HFFF     I  RRRRR  E
     4EE    SSSSS  =====     T     3333 /5X,50HF        I  RR     E
     5 S              T       3/5X,50HF        I  R R    E          S
     6    T          3/5X,50HF        I  R  R   E            S          T
     7    3/5X,50HF        I  R   R  EEEEE  SSSSS            T     33333///)
  140 FORMAT (7X49HA THERMAL ANALYZER FOR THREE-DIMENSIONAL SYSTEMS,/7X,
     1,46HWITH TEMPERATURE-DEPENDENT THERMAL PROPERTIES,,/7X,31HSUBJECTE
     2D TO A FIRE ENVIRONMENT,///)
  150 FORMAT (///18X,24H- - - TITLE OF RUN - - -,//1X,6A10///)
  160 FORMAT (80R1)
  170 FORMAT (6(/),45H - - - PROGRAM TERMINATED - INPUT ERROR - - -,//1X
     1,80R1)
  180 FORMAT (////37H STOP - INCREASE BLANK COMMON SIZE TO,I10)
      END
      FUNCTION NUMBER (I)
C
C
C     FUNCTION *NUMBER* OBTAINS AN INTEGER CONSTANT CONTAINED
C     ON AN ALPHA-NUMERIC CONTROL CARD.  THE INTEGER CONSTANT MUST
C     BE CONTAINED BETWEEN COMMAS OR BETWEEN A COMMA AND A BLANK.
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
C
      K=0
   10 J=IREAD(I)
      IF (J.EQ.56B) GO TO 20
      IF (J.GT.32B) GO TO 40
      I=I+1
      IF (I.EQ.81) GO TO 30
      GO TO 10
   20 I=I+1
      J=IREAD(I)
      IF (J.EQ.55B.OR.J.EQ.56B) GO TO 30
      IF (J.LT.33B.OR.J.GT.44B) GO TO 40
      J=J-33B
      K=K*10+J
      GO TO 20
   30 NUMBER=K
      RETURN
C
   40 CONTINUE
      PRINT 50, (IREAD(J),J=1,80)
      STOP
C
C
C
   50 FORMAT (///,33H - - - PROGRAM TERMINATED - - - -,//,13H  INPUT ERR
     1OR,/1X,80R1)
      END
```

```
      SUBROUTINE NODE (X,Y,Z,KODE,ID,NTBC)
C
C
C     SUBROUTINE *NODE* INPUTS NODAL COORDINATES AND SETS
C     THE FLOW AND TEMPERATURE BOUNDARY CONDITIONS
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION X(1), Y(1), Z(1), KODE(1), ID(1)
C
C     OUTPUT PAGE HEADING
C
      WRITE (NOUT,100)
      WRITE (NOUT,110)
      WRITE (NOUT,120) ITITLE
      WRITE (NOUT,130)
      WRITE (NOUT,110)
      WRITE (NOUT,140) NUMNP
      WRITE (NOUT,150)
```

```
C
C     INITIALIZE BOUNDARY CONDITIONS TO FLOW
C
      DO 10 I=1,NUMNP
   10 KODE(I)=4HFLOW
C
C     INPUT NODAL COORDINATES
C
      L=1
   20 READ (NIN,160) N,X(N),Y(N),Z(N)
      IF (N.GE.L) GO TO 40
C
   30 WRITE (NOUT,170) N,X(N),Y(N),Z(N)
      STOP
C
   40 IF (N.EQ.L) GO TO 60
      IF (L.EQ.1) GO TO 30
C
C     WHEN N .GE. L THE PROGRAM GENERATES INTERMEDIATE NODES
C     AT INTERVALS OF DX, DY, AND DZ
C
      DIFF=N+1-L
      DX=(X(N)-X(L-1))/DIFF
      DY=(Y(N)-Y(L-1))/DIFF
      DZ=(Z(N)-Z(L-1))/DIFF
   50 X(L)=X(L-1)+DX
      Y(L)=Y(L-1)+DY
      Z(L)=Z(L-1)+DZ
      L=L+1
      IF (N.GT.L) GO TO 50
   60 L=L+1
      IF (N.LT.NUMNP) GO TO 20
      IF (N.NE.NUMNP) GO TO 30
      IF (NTBC.EQ.0) GO TO 80
C
C     INPUT KNOWN TEMPERATURE BOUNDARY CONDITIONS
C
      READ (NIN,180) (ID(I),I=1,NTBC)
      DO 70 I=1,NTBC
      J=ID(I)
      IF (J.LE.0.OR.J.GT.NUMNP) GO TO 90
   70 KODE(J)=4HTEMP
C
C     OUTPUT NODAL COORDINATES AND BOUNDARY CONDITION CODE
C
   80 WRITE (NOUT,190) (I,X(I),Y(I),Z(I),KODE(I),I=1,NUMNP)
      RETURN
C
   90 WRITE (NOUT,200)
      STOP
C
C
C
  100 FORMAT (1H1,5(/))
  110 FORMAT (61H ******************************************************
     1******)
  120 FORMAT (/5X50HFIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL,/
     1/1X,(A10)
  130 FORMAT (/7X,46HGEOMETRIC DESCRIPTION OF SYSTEM TO BE ANALYZED,/)
  140 FORMAT (//,20H  . . . . THERE ARE ,I5,22H NODAL POINTS . . . . )
  150 FORMAT (//,6H NODAL,24X,11HCOORDINATES,12X,8HBOUNDARY,/,6H POINT,9
     1X,1HX,14X,1HY,14X,1HZ,6X,9HCONDITION,/)
```

```
FIRES-T3  488            160 FORMAT (I5,3E10.0)
FIRES-T3  489            170 FORMAT (5(/),51H  - - - PROGRAM TERMINATED - NODE INPUT ERROR - -
FIRES-T3  490               1-,//1X,I5,3F10.4)
FIRES-T3  491            180 FORMAT (16I5)
FIRES-T3  492            190 FORMAT (I5,3F15.4,7X,A4)
FIRES-T3  493            200 FORMAT (5(/),33H  - - - PROGRAM TERMINATED - - - ,/,47H  ERROR IN
FIRES-T3  494               1TEMPERATURE BOUNDARY CONDITION INPUT)
FIRES-T3  495                END



FIRES-T3  496                SUBROUTINE ELEMENT (X,Y,Z,LM,MMTYPE,BAREA,THICK,VOLUME)
FIRES-T3  497          C
FIRES-T3  498          C
FIRES-T3  499          C     SUBROUTINE *ELEMENT* INPUTS ELEMENT DATA
FIRES-T3  500          C
FIRES-T3  501          C
FIRES-T3  502                COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
FIRES-T3  503               1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NHCMAT,NHCTYP
FIRES-T3  504                DIMENSION X(1), Y(1), Z(1), LM(1), KX(8), MMTYPE(1), BAREA(1), THI
FIRES-T3  505               1CK(1), VOLUME(1)
FIRES-T3  506                DIMENSION SI(8), TI(8), UI(8), XX(8), YY(8), ZZ(8), B(3,8), PSTU(8
FIRES-T3  507               1), DPSTU(3,8), CJAC(3,3), POS(2)
FIRES-T3  508                DATA POS/-0.57735027,+0.57735027/
FIRES-T3  509                DATA SI/-1.,1.,1.,-1.,-1.,1.,1.,-1./
FIRES-T3  510                DATA TI/-1.,-1.,1.,1.,-1.,-1.,1.,1./
FIRES-T3  511                DATA UI/-1.,-1.,-1.,-1.,1.,1.,1.,1./
FIRES-T3  512          C
FIRES-T3  513          C
FIRES-T3  514          C     O N E - D I M E N S I O N A L   E L E M E N T S
FIRES-T3  515          C
FIRES-T3  516          C
FIRES-T3  517                MBAND=0
FIRES-T3  518                IF (NEL1D.EQ.0) GO TO 80
FIRES-T3  519                NLM=0
FIRES-T3  520                NUM=0
FIRES-T3  521                WRITE (NOUT,360) NEL1D
FIRES-T3  522                WRITE (NOUT,370)
FIRES-T3  523                DO 70 N=1,NEL1D
FIRES-T3  524                NLM=NLM+2
FIRES-T3  525                IF (NUM-N) 10,20,20
FIRES-T3  526          C
FIRES-T3  527          C     READ ELEMENT CARD
FIRES-T3  528          C
FIRES-T3  529             10 READ (NIN,420) NUM,KX(1),KX(2),MTYPE,BA
FIRES-T3  530                IF (BA.EQ.0.0) BA=1.0
FIRES-T3  531                IF (NUM.GT.NEL1D) GO TO 40
FIRES-T3  532                IF (N.EQ.1) GO TO 30
FIRES-T3  533          C
FIRES-T3  534          C     GENERATE LM ARRAY
FIRES-T3  535          C
FIRES-T3  536             20 LM(NLM-1)=LM(NLM-3)+1
FIRES-T3  537                LM(NLM)=LM(NLM-2)+1
FIRES-T3  538                MMTYPE(N)=MMTYPE(N-1)
FIRES-T3  539                BAREA(N)=BAREA(N-1)
FIRES-T3  540             30 IF (NUM-N) 40,50,60
FIRES-T3  541          C
FIRES-T3  542          C     ERROR IN INPUT CARDS
FIRES-T3  543          C
FIRES-T3  544             40 WRITE (NOUT,450) NUM,KX(1),KX(2),MTYPE,BA
```

```
      STOP
C
   50 LM(NLM-1)=KX(1)
      LM(NLM)=KX(2)
      MMTYPE(N)=MTIPE
      BAREA(N)=BA
C
C     OUTPUT
C
   60 WRITE (NOUT,480) N,LM(NLM-1),LM(NLM),MMTYPE(N),BAREA(N)
C
C     DETERMINE BANDWIDTH AND STORE IF MAXIMUM
C
      J=LM(NLM-1)-LM(NLM)+1
      K=LM(NLM)-LM(NLM-1)+1
      IF (J.GT.MBAND) MBAND=J
      IF (K.GT.MBAND) MBAND=K
   70 CONTINUE
C
C
C     T W O - D I M E N S I O N A L   E L E M E N T S
C
C
   80 IF (NEL2D.EQ.0) GO TO 180
      NLM=2*NEL1D
      NUM=0
      WRITE (NOUT,380) NEL2D
      WRITE (NOUT,400)
      DO 170 N=1,NEL2D
      N1=N+NEL1D
      NLM=NLM+4
      IF (NUM-N) 90,100,100
C
C     READ ELEMENT CARD
C
   90 READ (NIN,430) NUM,KX(1),KX(2),KX(3),KX(4),MTIPE,THK
      IF (THK.EQ.0.0) THK=1.0
      IF (NUM.GT.NEL2D) GO TO 120
      IF (N.EQ.1) GO TO 110
C
C     GENERATE LM ARRAY
C
  100 LM(NLM-3)=LM(NLM-7)+1
      LM(NLM-2)=LM(NLM-6)+1
      LM(NLM-1)=LM(NLM-5)+1
      LM(NLM)=LM(NLM-4)+1
      MMTYPE(N1)=MMTYPE(N1-1)
      THICK(N)=THICK(N-1)
  110 IF (NUM-N) 120,130,140
C
C     ERROR IN INPUT CARD
C
  120 WRITE (NOUT,460) NUM,KX(1),KX(2),KX(3),KX(4),MTIPE,THK
      STOP
C
  130 LM(NLM-3)=KX(1)
      LM(NLM-2)=KX(2)
      LM(NLM-1)=KX(3)
      LM(NLM)=KX(4)
      MMTYPE(N1)=MTIPE
      THICK(N)=THK
C
```

```
C       OUTPUT
C
  140 WRITE (NOUT,490) N,LM(NLM-3),LM(NLM-2),LM(NLM-1),LM(NLM),MMTYPE(NI
     1),THICK(N)
C
C       DETERMINE BANDWIDTH AND STORE IF MAXIMUM
C
      DO 160 L=1,4
      I=LM(NLM-4+L)
      DO 160 M=1,4
      J=LM(NLM-4+M)-I+1
      IF (MBAND-J) 150,160,160
  150 MBAND=J
  160 CONTINUE
  170 CONTINUE
C
C
C       T H R E E - D I M E N S I O N A L   E L E M E N T S
C
C
  180 IF (NEL3D.EQ.0) GO TO 350
      REWIND 6
      NLM=2*NEL1D+4*NEL2D
      NUM=0
      WRITE (NOUT,390) NEL3D
      WRITE (NOUT,410)
      DO 340 N=1,NEL3D
      NI=N+NEL1D+NEL2D
      NLM=NLM+8
      IF (NUM-N) 190,200,200
C
C       READ ELEMENT CARD
C
  190 READ (NIN,440) NUM,(KX(I),I=1,8),MTIPE
      IF (NUM.GT.NEL3D) GO TO 230
      IF (N.EQ.1) GO TO 220
C
C       GENERATE LM ARRAY FOR MISSING ELEMENTS
C
  200 CONTINUE
      DO 210 I=1,8
  210 LM(NLM-8+I)=LM(NLM-16+I)+1
      MMTYPE(NI)=MMTYPE(NI-1)
  220 IF (NUM-N) 230,240,260
C
C       ERROR IN INPUT CARDS
C
  230 WRITE (NOUT,470) NUM,(KX(I),I=1,8),MTIPE
      STOP
C
  240 CONTINUE
      DO 250 I=1,8
  250 LM(NLM-8+I)=KX(I)
      MMTYPE(NI)=MTIPE
C
C       OUTPUT
C
  260 WRITE (NOUT,500) N,(LM(NLM-8+I),I=1,8),MMTYPE(NI)
C
C       DETERMINE BANDWIDTH AND STORE IF MAXIMUM
C
      DO 280 I=1,8
      I=LM(NLM-8+L)
      DO 280 M=1,8
      J=LM(NLM-8+M)-I+1
      IF (MBAND-J) 270,280,280
  270 MBAND=J
  280 CONTINUE
C
C     CALCULATE ELEMENT DATA NEEDED LATER IN ANALYSIS AND STORE ON
C     TAPE 6
C
      DO 290 I=1,8
      J=LM(NLM-8+I)
      XX(I)=X(J)
      YY(I)=Y(J)
  290 ZZ(I)=Z(J)
      VOL=0.
      DO 330 III=1,2
      DO 330 JJJ=1,2
      DO 330 KKK=1,2
      SE=POS(III)
      TE=PCS(JJJ)
      UE=POS(KKK)
      DO 300 I=1,8
      PSTU(I)=(1.+SE*SI(I))*(1.+TE*TI(I))*(1.+UE*UI(I))/8.
      DPSTU(1,I)=SI(I)*(1.+TE*TI(I))*(1.+UE*UI(I))/8.
      DPSTU(2,I)=TI(I)*(1.+SE*SI(I))*(1.+UE*UI(I))/8.
  300 DPSTU(3,I)=UI(I)*(1.+SE*SI(I))*(1.+TE*TI(I))/8.
      DO 310 I=1,3
      CJAC(I,1)=0.
      CJAC(I,2)=0.
      CJAC(I,3)=0.
      DO 310 J=1,8
      CJAC(I,1)=CJAC(I,1)+DPSTU(I,J)*XX(J)
      CJAC(I,2)=CJAC(I,2)+DPSTU(I,J)*YY(J)
  310 CJAC(I,3)=CJAC(I,3)+DPSTU(I,J)*ZZ(J)
      CALL INVMAT (CJAC,DETJ,3)
      VOL=VOL+DETJ
      DO 320 I=1,3
      DO 320 J=1,8
      B(I,J)=0.
      DO 320 K=1,3
  320 B(I,J)=B(I,J)+CJAC(I,K)*DPSTU(K,J)
      WRITE (6) DETJ,(PSTU(I),I=1,8),((B(I,J),J=1,8),I=1,3)
  330 CONTINUE
      VOLUME(N)=VOL
  340 CONTINUE
C
C
C     PRINT THE MAXIMUM BANDWIDTH
C
C
  350 WRITE (NOUT,510) MBAND
      RETURN
C
C
C
C
  360 FORMAT (///20H    . . . . THERE ARE ,I5,23H  1-D ELEMENTS . . . . )
  370 FORMAT (//5H ELMT,15H     I     J  MAT,5X,5H AREA/)
  380 FORMAT (///20H    . . . . THERE ARE ,I5,23H  2-D ELEMENTS . . . . )
  390 FORMAT (///20H    . . . . THERE ARE ,I5,23H  3-D ELEMENTS . . . . )
  400 FORMAT (//5H ELMT,25H     I     J     K     L  MAT,5X,10H THICKNESS/)
  410 FORMAT (//5H ELMT,50H     I     J     K     L     M     N     C     P   MAT
     1     /)
  420 FORMAT (4I5,F10.0)
  430 FORMAT (6I5,F10.0)
  440 FORMAT (10I5)
  450 FORMAT (//20H ERROR IN EL INPUT  //4I5,F10.5)
  460 FORMAT (//20H ERROR IN EL INPUT  //6I5,F10.5)
  470 FORMAT (//20H ERROR IN EL INPUT  //10I5)
  480 FORMAT (4I5,F10.5)
  490 FORMAT (6I5,F15.5)
  500 FORMAT (10I5)
  510 FORMAT (///,31H    . . . MAXIMUM BANDWIDTH IS ,I4,6H . . .)
      END
```

```
      SUBROUTINE INVMAT (A,DETJ,NDIM)
C
C
C     SUBROUTINE *INVMAT* INVERTS THE JACOBIAN MATRIX
C
C
      DIMENSION A(3,3), COFTR(3,3)
C
C
      IF (NDIM.EQ.3) GO TO 20
C
C     2-D JACOBIAN
C
      DETJ=A(1,1)*A(2,2)-A(1,2)*A(2,1)
      COFTR(1,1)=A(2,2)
      COFTR(1,2)=-A(2,1)
      COFTR(2,1)=-A(1,2)
      COFTR(2,2)=A(1,1)
      DO 10 I=1,2
      DO 10 J=1,2
   10 A(I,J)=COFTR(J,I)/DETJ
      RETURN
C
C     3-D JACOBIAN
C
   20 DETJ=A(1,1)*(A(2,2)*A(3,3)-A(2,3)*A(3,2))-A(1,2)*(A(2,1)*A(3,3)-A(
     12,3)*A(3,1))+A(1,3)*(A(2,1)*A(3,2)-A(2,2)*A(3,1))
      COFTR(1,1)=A(2,2)*A(3,3)-A(2,3)*A(3,2)
      COFTR(1,2)=-A(2,1)*A(3,3)+A(2,3)*A(3,1)
      COFTR(1,3)=A(2,1)*A(3,2)-A(2,2)*A(3,1)
      COFTR(2,1)=-A(1,2)*A(3,3)+A(1,3)*A(3,2)
      COFTR(2,2)=A(1,1)*A(3,3)-A(1,3)*A(3,1)
      COFTR(2,3)=-A(1,1)*A(3,2)+A(1,2)*A(3,1)
      COFTR(3,1)=A(1,2)*A(2,3)-A(1,3)*A(2,2)
      COFTR(3,2)=-A(1,1)*A(2,3)+A(1,3)*A(2,1)
      COFTR(3,3)=A(1,1)*A(2,2)-A(1,2)*A(2,1)
      DO 30 I=1,3
      DO 30 J=1,3
   30 A(I,J)=COFTR(J,I)/DETJ
      RETURN
      END
      SUBROUTINE MATRIAL (MATL,XYS,NSTORE)
C
C
C     SUBROUTINE *MATRIAL* INPUTS THE NECESSARY MATERIAL PROPERTIES.
C     THE VALUES OF THESE PROPERTIES ARE EITHER IN THE FORM OF A
C     CONSTANT OR A LINEARIZED FUNCTION OF TEMPERATURE.
C     NSTORE CONTAINS THE STARTING LOCATION FOR STORING THE LINEARIZED
C     MATERIAL PROPERTY FUNCTIONS AND ALSO RETURNS THE REQUIRED STORAGE
C     FOR XYS TO FIRES-T3.
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION MATL(1), XYS(1)
      NSTORE=1
C
C     OUTPUT PAGE HEADING
C
      WRITE (NOUT,20)
      WRITE (NOUT,30)
      WRITE (NOUT,40) ITITLE
      WRITE (NOUT,50) NMAT
      WRITE (NOUT,30)
C
      DO 10 M=1,NMAT
      WRITE (NOUT,60) M
C
C     READ IN CONTROL VARIABLES. IF INTEGER VARIABLE IS ZERO THAN
C     MATERIAL VALUE IS CONSTANT. IF INTEGER CONSTANT IS GREATER THAN
C     2  THEN IT IS THE NUMBER OF POINTS REQUIRED TO DESCRIBE THE
C     LINEARIZED TEMPERATURE DEPENDENT FUNCTION
C
      READ (NIN,70) MK,MCP,MD
      MS=(M-1)*6
C
C     INPUT CONDUCTIVITY DATA
C
      WRITE (NOUT,80)
      MATL(MS+1)=NSTORE
      MATL(MS+2)=MK
      CALL MATIN (MK,XYS(NSTORE),XYS(NSTORE+MK),XYS(NSTORE+MK+MK))
      NSTORE=NSTORE+3*MK
      IF (MK.EQ.0) NSTORE=NSTORE+1
C
C     INPUT SPECIFIC HEAT DATA
C
      WRITE (NOUT,90)
      MATL(MS+3)=NSTORE
      MATL(MS+4)=MCP
      CALL MATIN (MCP,XYS(NSTORE),XYS(NSTORE+MCP),XYS(NSTORE+MCP+MCP))
      NSTORE=NSTORE+3*MCP
      IF (MCP.EQ.0) NSTORE=NSTORE+1
C
C     INPUT DENSITY DATA
C
      WRITE (NOUT,100)
      MATL(MS+5)=NSTORE
      MATL(MS+6)=MD
      CALL MATIN (MD,XYS(NSTORE),XYS(NSTORE+MD),XYS(NSTORE+MD+MD))
      NSTORE=NSTORE+3*MD
      IF (MD.EQ.0) NSTORE=NSTORE+1
C
```

```
   10 CONTINUE
C
      RETURN
C
C
   20 FORMAT (1H6,5(/))
   30 FORMAT (61H ******************************************************
     1******)
   40 FORMAT (/5X50HFIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL,/
     1/1X,6A10)
   50 FORMAT (/5X,43HTHERMAL PROPERTIES OF SYSTEM TO BE ANALYZED,//,5X,1
     10HTHERE ARE ,I3,20H DIFFERENT MATERIALS,/)
   60 FORMAT (////,26H  . . . . MATERIAL NUMBER ,I4,9H  . . . .)
   70 FORMAT (3I5)
   80 FORMAT (//7X,25H . . . CONDUCTIVITY . . .,)
   90 FORMAT (//7X,26H . . . SPECIFIC HEAT . . .)
  100 FORMAT (//7X,20H . . . DENSITY . . .)
      END
```

```
      SUBROUTINE MATIN (K,X,Y,S)
C
C
C     SUBROUTINE *MATIN* INPUTS FOR EACH MATERIAL ITS TEMPERATURE -
C     DEPENDENT PROPERTIES, CALCULATES SLOPES, AND PRINTS THE DATA.
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION X(1), Y(1), S(1)
C
      IF (K.NE.0) GO TO 10
C
C     INPUT CONSTANT VALUE FUNCTION
C
      READ (NIN,50) X(1)
      WRITE (NOUT,60) X(1)
      RETURN
C
C     INPUT VARIABLE VALUE FUNCTION
C
   10 CONTINUE
C
C     CHECK K FOR AN ALLOWABLE NUMBER OF POINTS IN MATERIAL FUNCTION
C
      IF (K.EQ.1.OR.K.LT.0) GO TO 40
      READ (NIN,50) (X(I),Y(I),I=1,K)
      M=K-1
C
C     DETERMINE THE SLOPES OF THE LINEAR SEGMENTS OF THE MATERIAL
C     FUNCTIONS
C
      DO 20 I=1,M
   20 S(I)=(Y(I+1)-Y(I))/(X(I+1)-X(I))
      WRITE (NOUT,70)
C
C     OUTPUT THE FUNCTION IF IT IS VARIABLE
C
      DO 30 I=1,M
      WRITE (NOUT,80) I,X(I),Y(I)
      WRITE (NOUT,90) S(I)
   30 CONTINUE
      WRITE (NOUT,80) K,X(K),Y(K)
      RETURN
C
C
   40 WRITE (NOUT,100) K
      STOP
C
C
   50 FORMAT (8E10.0)
   60 FORMAT (/,39H  MATERIAL PARAMETER OF CONSTANT VALUE ,G11.3)
   70 FORMAT (/5X,19HNODE    TEMPERATURE,6X,5HVALUE,7X,5HSLOPE,/)
   80 FORMAT (I9,F13.1,6X,G11.3)
   90 FORMAT (39X,G11.3)
  100 FORMAT (///,44H  ------------PROGRAM TERMINATED------------,/,14H
     1  INPUT ERROR,/,23H   CONTROL CONSTANT IS ,I5,22H AND IT MUST BE E
     2ITHER,/,34H    0 OR GREATER THAN OR EQUAL TO 2)
      END
```

```
      FUNCTION VMAT (K,X,Y,S,T,NAME)
C
C
C     FUNCTION *VMAT* CALCULATES THE VALUE OF THE TEMPERATURE-DEPENDENT
C     VARIABLES REQUIRED IN THE THERMAL ANALYSIS
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION X(1), Y(1), S(1)
C
      IF (K.NE.0) GO TO 10
      VMAT=X(1)
      RETURN
C
   10 I=0
   20 I=I+1
      IF (I.GT.K) GO TO 50
      IF (T-X(I)) 40,30,20
   30 VMAT=Y(I)
      RETURN
C
   40 IF (I.EQ.1) GO TO 50
      VMAT=Y(I-1)+S(I-1)*(T-X(I-1))
      RETURN
C
C
   50 WRITE (NOUT,60) NAME,T,X(1),X(K)
      STOP
C
C
C
   60 FORMAT (///,48H  --------------PROGRAM TERMINATED --------------,/,
     150H     BOUNDS OF CURVE DESCRIBING MATERIAL PARAMETER ,A10,15H HAVE
     2 BEEN EXCEEDED,/,23H    THE TEMPERATURE WAS ,F10.3,20H THE LOWER BO
     3UND IS ,F10.3,24H AND THE UPPER BOUND IS ,F10.3)
      END
      SUBROUTINE CONVERG (NTOTAL)
C
C
C     SUBROUTINE *CONVERG* INPUTS THE CONVERGENCE CRITERIA CONTROLLING
C     THE NATURE OF THE THERMAL ANALYSIS.  THE PROGRAM CONTAINS THE
C     THE CAPABILITIES FOR ITERATIVE SOLUTIONS DEALING WITH  THE ENTIRE
C     SYSTEM AND/OR THE FIRE BOUNDARY CONDITIONS
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      COMMON /CONRG/ NCONV,CONV,BETA,NCONU,CONU,ALPHA
C
C     OUTPUT PAGE HEADING
C
      WRITE (NOUT,20)
      WRITE (NOUT,30)
      WRITE (NOUT,40) ITITLE
      WRITE (NOUT,50)
      WRITE (NOUT,30)
      WRITE (NOUT,60)
C
C     CONVERGENCE DETERMINED WHEN
C
C        2*ABS(T(I)-T(I-1)/T(I)+T(I-1) .LESS THAN. CONV OR CONU
C
C     AND IF CONVERGENCE IS NOT ACHIEVED THE NEXT ESTIMATE OF THE
C     SYSTEMS TEMPERATURES IS OBTAINED THROUGH
C
C        T(I+1) = T(I) + BETA (OR ALPHA) *(T(I)-T(I-1))
C
C        WHERE     SYSTEM         FIRE BC
C                  CRITERIA       CRITERIA
C
C                    NCONU          NCONV    - NUMBER OF PERMISSIBLE
C                                              ITERATIONS(0-IF PARTICULAR
C                                              ITERATION IS NOT DESIRED)
C                    CONU           CONV     - PERMISSIBLE RELATIVE ERROR
C                    ALPHA          BETA     - OVER RELAXATION FACTOR
C
C     INPUT CONVERGENCE CRITERIA
C
      READ (NIN,70) NCONV,CONV,BETA,NCONU,CONU,ALPHA
      IF (NCONU.EQ.0) GO TO 10
C
C     OUTPUT SYSTEM CONVERGENCE CRITERIA
C
      WRITE (NOUT,80) CONU,NCONU,ALPHA
   10 CONTINUE
C
C     OUTPUT FIRE BOUNDARY CONDITION CONVERGENCE CRITERIA
C
      WRITE (NOUT,90) CONV,NCONV,BETA
C
C     DIVIDE PERMISSBLE ERROR BY TWO
C
      CONV=CONV*0.50
      CONU=CONU*0.50
C
C
C     STORAGE REQUIREMENT FOR BLANK COMMON IS NOW PRINTED
C
```

```
C
      WRITE (NOUT,100) NTOTAL,NTOTAL
      RETURN
C
C
   20 FORMAT (1H6,5(/))
   30 FORMAT (61H ******************************************************
     1******)
   40 FORMAT (/5X50HFIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL,/
     1/1X,6A10)
   50 FORMAT (/5X,46HINFORMATION RELEVANT TO THE ANALYSIS PROCEDURE,/)
   60 FORMAT (////38H  . . . . CONVERGENCE CRITERIA . . . .)
   70 FORMAT (I5,2F10.0,I5,2F10.0)
   80 FORMAT (//40H  CONVERGENCE CRITERIA FOR ENTIRE SYSTEM//,23H     PER
     1MISSIBLE ERROR =,F10.5/,34H     MAXIMUM NUMBER OF ITERATIONS =,I5/,
     212H     ALPHA =,F10.4)
   90 FORMAT (//,46H  CONVERGENCE CRITERIA FOR BOUNDARY CONDITIONS//,24H
     1      PERMISSIBLE ERROR =,F10.5/,35H      MAXIMUM NUMBER OF ITERATIO
     2NS =,I5,11H      BETA =,F10.4)
  100 FORMAT (////,54H  . . . . STORAGE REQUIREMENT FOR BLANK COMMON . .
     1 . .,//5X,20HSIZE BLANK COMMON = ,I10,10H (DECIMAL),/23X,5H=     ,O
     27,8H (OCTAL))
      END
```

```
      SUBROUTINE HEATFLO (X,Y,Z,KODE,D,MA,T1,T2,T3,LM,MMTYPE,BAREA,THICK
     1,MATL,XYS,MAT,FXYS,LI,LJ,LK,LL,LMAT,LFIRE,AIJKL,LELEM,IEXO,EXYS,IE
     2L,IMAT,VEL,Q,T,B,AT,A,VOLUME,NP,NUMFBC)
C
C
C     SUBROUTINE *HEATFLO* IS THE THERMAL ANALYSIS CONTROLLER
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      COMMON /EXOTH/ NINT1D,NINT2D,NINT3D,NINT,NQINT
      COMMON /CONRG/ NCONV,CONV,BETA,NCONU,CONU,ALPHA
      DIMENSION X(1), Y(1), Z(1), KODE(1), LM(1), MMTYPE(1), LELEM(1), M
     1ATL(1), XYS(1), MAT(1), FXYS(1), LI(1), LJ(1), LK(1), LL(1), LMAT(
     21), LFIRE(1), AIJKL(1), Q(1), T(1), B(1), AT(1), A(NP,1), D(1), MA
     3(1), T1(1), T2(1), T3(1), THICK(1), BAREA(1), IEXO(1), EXYS(1), IE
     4L(1), IMAT(1), VEL(1), VOLUME(1)
      DIMENSION TFIRE(4)
C
C     INITIALIZE THE SYSTEM
C
      IP1=0
      IP2=0
      SDT=0.0
      DS=0.0
C
C     INPUT INITIAL TIME STEP CARD
C     WHERE    IA - CONTROL WORD (STEP)
C              MDT - SEQUENCE COUNTER - INITIAL VALUE
C              TIME - SYSTEM CLOCK - INITIAL VALUE
C              TEMP - INDICATOR FOR INITIAL TEMPERATURE - IF NON-ZERO
C                     THEN TAKEN AS UNIFORM INITIAL TEMPERATURE OF SYSTEM
C              JP - IDENTIFIER FOR PUNCHED OUTPUT
C
```

```
      READ (NIN,370) IA,MDT,TIME,TEMP,JP
C
C     OUTPUT HEADING FOR INITIAL TIME STEP
C
      WRITE (NOUT,380)
      WRITE (NOUT,390)
      WRITE (NOUT,400) ITITLE
C
      IF (IA.NE.4HSTEP) GO TO 40
C
      WRITE (NOUT,410) MDT,TIME
      WRITE (NOUT,390)
C
C     INITIALIZE TEMPERATURES
C
      IF (TEMP.NE.0.0) GO TO 10
      READ (NIN,420) (T(I),I=1,NUMNP)
      GO TO 30
   10 DO 20 I=1,NUMNP
   20 T(I)=TEMP
C
C     OUTPUT INITIAL TEMPERATURES
C
   30 CALL PROUT (4,T,AT,LM,TI,D,MAIN,NCON,I)
      GO TO 50
C
   40 CONTINUE
C
C     TERMINATE PROGRAM - INITIAL TIME STEP CARD ERROR
C
      WRITE (NOUT,430) IA,MDT,TIME,TEMP,JP
      STOP
C
   50 CONTINUE
C
C     READ TIME STEP CARD
C     WHERE   IA - CONTROL WORD (STEP)
C             NDT - SEQUENCE NUMBER
C             DT - TIME STEP INTERVAL
C             ITOF - NUMBER OF NON-ZERO TEMPERATURE OR FLOW B.C.
C             TFIRE(I) - TEMPERATURE OF FIRE FOR CURRENT TIME STEP
C                        I CAN VARY FROM 1 TO 4
C             I1 - PRINTED OUTPUT OPTION
C                  0 - NO PRINTED OUTPUT
C                  1 - OUTPUT NODAL POINT TEMPERATURES
C                  2 - OUTPUT ELEMENT TEMPERATURES
C                  3 - OUTPUT BOTH NODAL AND ELEMENT TEMPERATURES
C             I2 - PUNCHED OUTPUT OPTION
C                  CODE SAME AS FOR PRINTED DATA
C             I6 - DEBUGGING OUTPUT OPTION
C             I7 - CHANGE OF FIRE SURFACE ELEMENTS OPTION
C
   60 READ (NIN,440) IA,NDT,DT,ITOF,TFIRE(1),TFIRE(2),TFIRE(3),TFIRE(4),
     1I1,I2,I6,I7
      MAIN=0
      NDT=NDT+1
C
C     CHECK SEQUENCING OF TIME STEP CARD
C
      IF (NDT.EQ.MDT.AND.IA.EQ.4HSTEP) GO TO 90
C
C     PROGRAM TERMINATED IF SEQUENCING ERROR
```

```
C
      WRITE (NOUT,450)
   70 WRITE (NOUT,460) IA,NDT,DT,ITOF,TFIRE(1),TFIRE(2),TFIRE(3),TFIRE(4
     1),I1,I2,I6,I7
      STOP
   80 WRITE (NOUT,470)
      GO TO 70
C
C     ESTABLISH TIME INTERVAL DT
C
   90 IF (DT) 100,110,120
  100 WRITE (NOUT,480)
      RETURN
C
  110 IF (DS.EQ.0.0) GO TO 80
      DT=DS
      GO TO 130
  120 DS=DT
  130 CONTINUE
C
      TIME=TIME+DT
C
C     OUTPUT HEADING FOR TIME STEP
C
      WRITE (NOUT,380)
      WRITE (NOUT,390)
      WRITE (NOUT,400) ITITLE
      WRITE (NOUT,490) NDT,TIME,DT
      WRITE (NOUT,390)
      WRITE (NOUT,500) ITOF
      IF (NUMFBC.EQ.0) GO TO 140
      WRITE (NOUT,510) (I,TFIRE(I),I=1,4)
  140 CONTINUE
      DT2=1./DT
C
C
C     B E G I N N I N G   O F   S Y S T E M   I T E R A T I O N
C
C
  150 MAIN=MAIN+1
C
C     SAVE THE INITIALLY ASSUMED TEMPERATURES IN VECTOR T1
C
      DO 160 N=1,NUMNP
  160 T1(N)=T(N)
      IF (I6.NE.0) CALL PROUT (1,T,AT,LM,T1,B,MAIN,NCON,I1)
C
C     FORM CONDUCTIVITY MATRIX AND STORE IN MATRIX A, AND ALSO FORM
C     THE HEAT CAPACITY MATRIX AND STORE IN VECTOR Q
C
      CALL HCONDC (AT,A,NUMNP,MATL,XYS,T,Q,LM,MMTYPE,BAREA,THICK,X,Y,Z,V
     1OLUME)
C
C     INITIALIZE HEAT LOAD VECTOR TO 0.0 - VECTOR H
C
      DO 170 I=1,NUMNP
  170 H(I)=0.0
C
C     ADD INTERNAL HEAT GENERATION TO VECTOR H
C
      IF (NINT.EQ.0) GO TO 180
      CALL CEXC (LM,IEL,IMAT,IEXO,EXYS,AT,MATL,VEL,MMTYPE,B,XYS,TIME)
```

```
C
C      INPUT ANY NON-ZERO TEMPERATURE AND FLOW BOUNDARY CONDITONS
C      AND ADD THE RELATED TERMS TO MATRIX A AND VECTOR B
C      .
  180 CALL HATEMP (ITOF,O,KODE,B,A,NUMNP,MAIN,T3,C)
C
C      ADD CAPACITY TERMS TO CONDUCTIVITY MATRIX A
C
      DO 200 N=1,NUMNP
      IF (KODE(N).EQ.4HTEMP) GO TO 200
      IF (C(N)) 190,200,190
  190 A(N,1)=A(N,1)+Q(N)*DT2
  200 CONTINUE
C
C      TRIANGULARIZE THE MODIFIED CONDUCTIVITY MATRIX
C
      CALL MSYM (1,B,MA,A,NUMNP)
C
      IF (MAIN.NE.1) GO TO 220
C
C      CALCULATE EFFECTIVE LOAD VECTOR B
C
C      CALCULATE CAPACITY MATRIX CONTRIBUTION TO THE EFFECTIVE LOAD
C      AND SAVE IN VECTOR T2
C
      DO 210 II=1,NUMNP
      IF (KODE(II).EQ.4HTEMP) GO TO 210
      T2(II)=Q(II)*T(II)*DT2
  210 CONTINUE
  220 DO 230 II=1,NUMNP
      IF (KODE(II).EQ.4HTEMP) GO TO 230
      B(II)=B(II)+T2(II)
  230 Q(II)=B(II)
      NCON=0
      IF (NUMFBC.EQ.0) GO TO 260
C
C      IF FIRE BOUNDARY CONDITION SURFACE CONFIGURATION IS TO BE CHANGED
C      ON THIS TIME STEP, INPUT THE NEW DATA
C
      IF (I7.EQ.0) GO TO 250
      CALL FIREBC (X,Y,Z,KODE,BAREA,THICK,LI,LJ,LK,LL,LMAT,LFIRE,AIJKL,L
     1ELEM)
C
C
C      B E G I N N I N G   O F   F I R E   B.   C.   I T E R A T I O N
C
C
  240 CONTINUE
C
C      CALCULATE THE HEAT FLOW RELATED TO THE FIRE B.C.
C
  250 CALL FIRE (LI,LJ,LK,LL,LMAT,LFIRE,AIJKL,MAT,FXYS,T,TFIRE,B)
      NCON=NCON+1
C
C      CALCULATE THE TEMPERATURES THROUGH BACK SUBSTITUTION
C
  260 CALL MSYM (2,B,MA,A,NUMNP)
C
      IF (NUMFBC.EQ.0) GO TO 280
      IF (NCONV.EQ.0) GO TO 240
      IF (I6.NE.0) CALL PROUT (2,T,AT,LM,T1,B,MAIN,NCON,I1)
C
```

```
C     CHECK FOR CONVERGENCE OF FIRE B.C. CYCLE AGAINST PERMISSIBLE ERROR
C
      DO 270 N=1,NUMNP
      DX=ABS(B(N)-T(N))
      DY=CONV*ABS(B(N)+T(N))
      IF (DX.GT.DY) GO TO 300
  270 CONTINUE
  280 DO 290 N=1,NUMNP
  290 T(N)=B(N)
      GO TO 320
C
C     IF CONVERGENCE NOT OBTAINED CHECK FOR POSSIBILITY OF EXCEEDING
C     PERMISSIBLE NUMBER OF CYCLES FOR FIRE B.C.
C
  300 IF (NCON.GT.NCONV) CALL PROUT (3,T,AT,LM,T1,B,MAIN,NCON,I1)
C
C     ESTIMATE NEW APPROXIMATION OF TEMPERATURES FOR FIRE B.C.
C
      DO 310 JJ=1,NUMNP
      DX=B(JJ)-T(JJ)
      T(JJ)=B(JJ)+BETA*DX
  310 B(JJ)=C(JJ)
      GO TO 240
C
  320 IF (NCONU.EQ.0) GO TO 360
C
C     CHECK CONVERGENCE OF SYSTEM CYCLE AGAINST PERMISSIBLE ERROR
C
      DO 330 N=1,NUMNP
      DX=ABS(T(N)-T1(N))
      DY=CONU*ABS(T(N)+T1(N))
      IF (DX.GT.DY) GO TO 340
  330 CONTINUE
      GO TO 360
C
C     CHECK TO SEE IF NUMBER OF SYSTEM ITERATIONS HAS EXCEEDED
C     PERMISSIBLE NUMBER OF ITERATIONS
C
  340 IF (MAIN.GT.NCONU) CALL PROUT (3,T,AT,LM,T1,B,MAIN,NCON,I1)
C
C     ESTIMATE NEW APPROXIMATION OF SYSTEMS TEMPERATURES
C
      DO 350 N=1,NUMNP
      DX=T(N)-T1(N)
  350 T(N)=T(N)+ALPHA*DX
      GO TO 150
  360 CONTINUE
C
C     CHECK FOR DESIRED OUTPUT
C
      IF (I1.NE.0) CALL PROUT (4,T,AT,LM,T1,B,MAIN,NCON,I1)
      IF (I2.NE.0) CALL PUOUT (I1,I2,T,AT,X,Y,Z,TIME,IP1,IP2,LM,JP)
      NC=NCON-1
      NS=MAIN-1
      WRITE (NOUT,530) NS
      WRITE (NOUT,520) NC
      GO TO 60
C
C
C
  370 FORMAT (A4,I6,2F10.0,2X,A3)
  380 FORMAT (1H0,5(/))
  390 FORMAT (61H ******************************************************
     1******)
  400 FORMAT (/5X50HFIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL,/
     1/1X,6A10)
  410 FORMAT (/1X,27HINITIAL SEQUENCE NUMBER IS ,I4,21H AND INITIAL TIME
     1 IS ,F8.2/)
  420 FORMAT (7(4X,F6.1))
  430 FORMAT (5(/),69H - - - - PROGRAM TERMINATED - ERROR IN INITIAL TIM
     1E STEP CARD - - - -,//1X,A4,I6,2F10.2,2X,A3)
  440 FORMAT (A4,I6,F10.0,I5,4F10.0,4I3)
  450 FORMAT (///,43H  TIME STEP CARD OUT OF SEQUENCE - CARD NO.,I5/,12H
     1  INPUT CARD)
  460 FORMAT (//,57H  - - - - PROGRAM TERMINATED - TIME STEP CARD WAS -
     1- - -,//1X,A4,I6,F10.2,I5,4F10.2,4I5)
  470 FORMAT (///,30H  NO TIME INTERVAL ESTABLISHED)
  480 FORMAT (///,19H  PROBLEM COMPLETED)
  490 FORMAT (/2X,17HTIME STEP NUMBER ,I4,8H - TIME ,F7.3,13H - TIME STE
     1P ,F7.3/)
  500 FORMAT (/5X,50H NUMBER OF NON-ZERO FLOW OR TEMPERATURE CONDITIONS,
     1I5)
  510 FORMAT (/5X,24H FIRE BOUNDARY CONDITION,4(/7X,5HFIRE(,I1,4H) = ,F1
     10.3,2X))
  520 FORMAT (I5,32H B. C. ITERATIONS WERE PERFORMED)
  530 FORMAT (//I5,33H SYSTEM ITERATIONS WERE PERFORMED)
      END


      SUBROUTINE HCONDC (AT,A,NP,MATL,XYS,T,Q,LM,MMTYPE,BAREA,THICK,X,Y,
     1Z,VOLUME)
C
C
C     SUBROUTINE *HCONDC* FORMS CONDUCTIVITY AND HEAT CAPACITY MATRICES
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION AT(1), A(NP,1), MATL(1), XYS(1), T(1), Q(1), S(8,8), LM(
     11), ESTU(8), B(3,8), MMTYPE(1), BAREA(1), THICK(1), X(1), Y(1), Z(
     21), FCS(2), SI(4), TI(4), XX(4), YY(4), DPSTU(2,4), CJAC(3,3), VOL
     3UME(1)
      DATA FCS/-0.57735027,+0.57735027/
      DATA SI/-1.,1.,1.,-1./
      DATA TI/-1.,-1.,1.,1./
C
C
C     INITIALIZE THE SYSTEMS CONDUCTIVITY MATRIX TO 0.0
C     AND THE SYSTEMS HEAT CAPACITY MATRIX TO 0.0
C
      DO 10 I=1,NUMNP
   10 Q(I)=0.
      MB=MBAND*NUMNP
      DO 20 I=1,MB
   20 A(I)=0.0
C
C
C     O N E - D I M E N S I O N A L   E L E M E N T S
C
C
      IF (NEL1D.EQ.0) GO TO [illegible]
      NLM=0
      DO 40 N=1,NEL1D
      NLM=NLM+2
      DO 30 I=1,2
      DO 30 J=1,2
   30 S(I,J)=0.0
      II=LM(NLM-1)
      KK=LM(NLM)
      AA=X(II)-X(KK)
      BB=Y(II)-Y(KK)
      CC=Z(II)-Z(KK)
      XL=SQRT(AA*AA+BB*BB+CC*CC)
      AT(N)=0.5*(T(II)+T(KK))
      TEMP=AT(N)
      MS=MMTYPE(N)
      MS=(MS-1)*6
      J=MATL(MS+1)
      K=MATL(MS+2)
      COND=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H   K(T)    )
      J=MATL(MS+3)
      K=MATL(MS+4)
      SPHT=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H   CP(T)   )
      J=MATL(MS+5)
      K=MATL(MS+6)
      DENS=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H    D(T)   )
      S(1,1)=BAREA(N)*COND/XL
      S(1,2)=-S(1,1)
      S(2,1)=S(1,2)
      S(2,2)=S(1,1)
      QSTORE=SPHT*DENS*XL*BAREA(N)/2.
C
C     ADD ELEMENT CONDUCTIVITY AND CAPACITY TO SYSTEM MATRICES
C
      Q(II)=Q(II)+QSTORE
      Q(KK)=Q(KK)+QSTORE
      A(II,1)=A(II,1)+S(1,1)
      JJ=KK-II+1
      IF (JJ.GT.0) A(II,JJ)=A(II,JJ)+S(1,2)
      JJ=II-KK+1
      IF (JJ.GT.0) A(KK,JJ)=A(KK,JJ)+S(1,2)
      A(KK,1)=A(KK,1)+S(2,2)
   40 CONTINUE
C
C
C     T W O - D I M E N S I O N A L   E L E M E N T S
C
C
   50 IF (NEL2D.EQ.0) GO TO 270
      NLM=2*NEL1D
      DO 260 N=1,NEL2D
      N1=N+NEL1D
      NLM=NLM+4
      DO 60 I=1,4
      DO 60 J=1,4
   60 S(I,J)=0.0
      LL1=LM(NLM-3)
      LL2=LM(NLM-2)
      LL3=LM(NLM-1)
      LL4=LM(NLM)
      AT(N1)=0.25*(T(LL1)+T(LL2)+T(LL3)+T(LL4))
C
C     TEST FOR ORIENTATION OF 2-D ELEMENT  -  X-Y, X-Z, OR Y-Z PLANE
```

```
C
      JO=LM(NLM-3)
      ZZZ=Z(JO)
      DO 7C I=1,3
      J=LM(NLM-3+I)
      DZ=AES(ZZZ-Z(J))
      IF (DZ.GT.0.00001) GO TO 90
   70 CONTINUE
      DO 80 I=1,4
      J=LM(NLM-4+I)
      XX(I)=X(J)
   80 YY(I)=Y(J)
      GO TO 160
   9C YYY=Y(JO)
      DO 100 I=1,3
      J=LM(NLM-3+I)
      DY=ABS(YYY-Y(J))
      IF (DY.GT.0.0000I) GO TO 120
  100 CONTINUE
      DO 11C I=1,4
      J=LM(NLM-4+I)
      XX(I)=X(J)
  110 YY(I)=Z(J)
      GO TC 160
  12C XXX=X(JO)
      DO 130 I=1,3
      J=LM(NLM-3+I)
      DX=ABS(XXX-X(J))
      IF (DX.GT.0.00001) GO TO 150
  130 CONTINUE
      DO 140 I=1,4
      J=LM(NLM-4+I)
      XX(I)=Y(J)
  140 YY(I)=Z(J)
      GO TO 160
  150 WPITE (NOUT,370) N
      STOP
  160 VOL=C.C
      DO 220 III=1,2
      DO 220 JJJ=1,2
      SF=POS(III)
      TF=PCS(JJJ)
      DO 170 I=1,4
      PSTU(I)=(1.+SF*SI(I))*(1.+TE*TI(I))/4.
      DPSTL(1,I)=SI(I)*(1.+TE*TI(I))/4.
  170 DPSTU(2,I)=TI(I)*(1.+SE*SI(I))/4.
      DO 180 I=1,2
      CJAC(I,1)=0.0
      CJAC(I,2)=0.0
      DO 180 J=1,4
      CJAC(I,1)=CJAC(I,1)+DPSTU(I,J)*XX(J)
  180 CJAC(I,2)=CJAC(I,2)+DPSTU(I,J)*YY(J)
      CALL INVMAT (CJAC,DETJ,2)
      VCL=VCL+DETJ*THICK(N)
      DO 190 I=1,2
      DO 190 J=1,4
      B(I,J)=0.0
      DO 190 K=1,2
  190 B(I,J)=B(I,J)+CJAC(I,K)*DPSTU(K,J)
      ATT=C.
      DO 200 I=1,4
      L=LM(NLM-4+I)
  200 ATT=ATT+PSTU(I)*T(L)
      TEMP=ATT
      MS=MMTYPE(N1)
      MS=(MS-1)*6
      J=MATL(MS+1)
      K=MATL(MS+2)
      COND=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H    K(T)    )
      J=MATL(MS+3)
      K=MATL(MS+4)
      SPHT=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H    CP(T)   )
      J=MATL(MS+5)
      K=MATL(MS+6)
      DENS=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H     D(T)   )
      DETCON=DETJ*COND*THICK(N)
      DO 210 I=1,4
      DO 210 J=1,4
      DO 210 K=1,2
  210 S(I,J)=S(I,J)+DETCON*B(K,I)*B(K,J)
  220 CONTINUE
      QSTORE=DENS*SPHT*VOL/4.
C
C     ADD ELEMENT CAPACITY MATRIX TO SYSTEM CAPACITY MATRIX
C
      DO 230 L=1,4
      I=LM(NLM-4+L)
  230 Q(I)=Q(I)+QSTORE
C
C     ADD ELEMENT CONDUCTIVITY TO SYSTEM CONDUCTIVITY MATRIX
C
      DO 250 L=1,4
      I=LM(NLM-4+L)
      DO 250 M=1,4
      J=LM(NLM-4+M)-I+1
      IF (J) 250,250,240
  240 A(I,J)=A(I,J)+S(L,M)
  250 CONTINUE
  260 CONTINUE
C
C
C     T H R E E - D I M E N S I O N A L   E L E M E N T S
C
C
  270 IF (NEL3D.EQ.0) GO TO 360
      REWIND 6
      NLM=2*NEL1D+4*NEL2D
      DO 350 N=1,NEL3D
      N1=N+NEL1D+NEL2D
      NLM=NLM+8
      DO 280 I=1,8
      DO 280 J=1,8
  280 S(I,J)=0.0
      LL1=LM(NLM-7)
      LL2=LM(NLM-6)
      LL3=LM(NLM-5)
      LL4=LM(NLM-4)
      LL5=LM(NLM-3)
      LL6=LM(NLM-2)
      LL7=LM(NLM-1)
      LL8=LM(NLM)
      AT(N1)=.125*(T(LL1)+T(LL2)+T(LL3)+T(LL4)+T(LL5)+T(LL6)+T(LL7)+T(LL
     18))
      DO 310 III=1,2
      DO 310 JJJ=1,2
      DO 310 KKK=1,2
      READ (6) DETJ,(PSTU(I),I=1,8),((B(I,J),J=1,8),I=1,3)
      ATT=0.
      DO 290 I=1,8
      L=LM(NLM-8+I)
  290 ATT=ATT+PSTU(I)*T(L)
      TEMP=ATT
      MS=MMTYPE(NI)
      MS=(MS-1)*6
      J=MATL(MS+1)
      K=MATL(MS+2)
      COND=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H    K(T)    )
      J=MATL(MS+3)
      K=MATL(MS+4)
      SPHT=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H    CP(T)   )
      J=MATL(MS+5)
      K=MATL(MS+6)
      DENS=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H     D(T)   )
      DETCON=DETJ*COND
      DO 300 I=1,8
      DO 300 J=1,8
      DO 300 K=1,3
  300 S(I,J)=S(I,J)+DETCON*B(K,I)*B(K,J)
  310 CONTINUE
      VOL=VOLUME(N)
      QSTORE=DENS*SPHT*VOL/8.
C
C     ADD ELEMENT CAPACITY MATRIX TO SYSTEM CAPACITY MATRIX
C
      DO 320 L=1,8
      I=LM(NLM-8+L)
  320 Q(I)=Q(I)+QSTORE
C
C     ADD ELEMENT CONDUCTIVITY TO THE SYSTEMS CONDUCTIVITY MATRIX - A
C
      DO 340 L=1,8
      I=LM(NLM-8+L)
      DO 340 M=1,8
      J=LM(NLM-8+M)-I+1
      IF (J) 340,340,330
  330 A(I,J)=A(I,J)+S(L,M)
  340 CONTINUE
  350 CONTINUE
C
  360 RETURN
C
C
  370 FORMAT (//31H STOP-ERROR IN 2-D ELEMENT NO. ,I5,/30H NOT IN X-Y, X
     1-Z, OR Y-Z PLANE)
      END
```

```
      SUBROUTINE HATEMP (ITOP,Q,KODE,P,A,NP,MAIN,FT,J)
C
C
C     SUBROUTINE *HATEMP* APPLIES THE FIXED TEMPERATURE OR FLOW
C     BOUNDARY CONDITIONS
C
```

```
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION D(1), KODE(1), B(1), A(NP,1), FT(1), J(1)
      IF (MAIN.NE.1) GO TO 30
C
C     INITIALIZE TEMPERATURE AND FLOW B.C. TO 0.0
C
      DO 10 I=1,NUMNP
   10 D(I)=0.0
C
      IF (ITOF.EQ.0) GO TO 30
C
      WRITE (NOUT,100)
C
C     INPUT NON-ZERO TEMPERATURE AND FLOW B.C.
C
      READ (NIN,110) (J(I),FT(I),I=1,ITOF)
      WRITE (NOUT,120)
C
C     OUTPUT THE NON-ZERO BOUNDARY CONDITIONS AND STORE IN MATRIX D
C
      DO 20 I=1,ITOF
      II=J(I)
      D(II)=FT(I)
      JJ=KODE(II)
      WRITE (NOUT,130) II,JJ,D(II)
   20 CONTINUE
C
   30 DO 90 N=1,NUMNP
C
C     MODIFY MATRIX B FOR FLOW B.C.
C
      B(N)=B(N)+D(N)
      IF (KODE(N).EQ.4HFLOW) GO TO 90
C
C     MODIFY A AND B MATRIX FOR TEMPERATURE B.C.
C
      DO 80 M=2,MBAND
      K=N-M+1
      IF (K) 50,50,40
   40 B(K)=B(K)-A(K,M)*D(N)
      A(K,M)=0.0
   50 L=N+M-1
      IF (NUMNP-L) 70,60,60
   60 B(L)=B(L)-A(N,M)*D(N)
   70 A(N,M)=0.0
   80 CONTINUE
      A(N,1)=1.0
      B(N)=D(N)
   90 CONTINUE
C
      RETURN
C
C
  100 FORMAT (//5X,31HVALUES OF TEMPERATURES OR FLOWS/10X,32HFOR NON-ZER
     1O BOUNDARY CONDITIONS)
  110 FORMAT (5(I5,F10.2))
  120 FORMAT (/,8H    NODE,7X,4HTYPE,10X,5HVALUE)
  130 FORMAT (I8,7X,A4,5X,F10.2)
      END
      SUBROUTINE MSYM (KKK,B,MA,A,NP)
C
C
C     SUBROUTINE *MSYM* IS AN EQUATION SOLVER
C     BASED ON A MODIFIED SYMSOL - VARIABLE BANDWIDTH WITH ZEROS IN BAND
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION B(1), MA(1), A(NP,1)
C
      NEQ=NUMNP
C
      GO TO (10,70), KKK
C
C     ******************************************************************
C
C     REDUCE MATRIX..... A
C
C     ******************************************************************
C
   10 NEQQ=NEQ-1
      DO 60 N=1,NEQQ
C
      M=MBAND
      DO 20 I=2,MBAND
      IF (A(N,M).NE.0.) GO TO 30
   20 M=M-1
   30 MA(N)=M
C
      I=N
      DO 50 L=2,M
      I=I+1
      CC=A(N,L)/A(N,1)
      IF (CC.EQ.0.) GO TO 50
      J=0
      DO 40 K=L,M
      J=J+1
   40 A(I,J)=A(I,J)-CC*A(N,K)
      A(N,L)=CC
   50 CONTINUE
   60 CONTINUE
      GO TO 120
C
C     ******************************************************************
C
C     REDUCE VECTOR..... B AND BACKSUBSTITUTE
C
C     ******************************************************************
C
   70 DO 90 N=1,NEQQ
      CC=B(N)
      IF (CC.EQ.0.) GO TO 90
      M=MA(N)
      I=N
      DO 80 L=2,M
      I=I+1
   80 B(I)=B(I)-CC*A(N,L)
      B(N)=CC/A(N,1)
   90 CONTINUE
      B(NEQ)=B(NEQ)/A(NEQ,1)
C
```

```
      NN=NEQ
      DO 110 N=1,NECQ
      NN=NN-1
      M=MA(NN)
      I=NN
      DO 100 K=2,M
      I=I+1
  100 B(NN)=B(NN)-A(NN,K)*B(I)
  110 CONTINUE
  120 RETURN
      END
```

```
      SUBROUTINE PROUT (K,T,AT,LM,T1,B,MAIN,NCON,I1)
C
C
C     SUBROUTINE *PROUT* PRINTS TEMPERATURE DISTRIBUTIONS
C       ( BOTH NODAL AND ELEMENT )
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION T(1), AT(1), T1(1), B(1), LM(1)
C
C
      GO TO (10,20,30,40), K
C
   10 CONTINUE
C
C     DEBUGGING OUTPUT FOR TEMPERATURES AT BEGINNING OF SYSTEM CYCLE
C
      WRITE (NOUT,140) MAIN
      WRITE (NOUT,230) (N,T(N),N=1,NUMNP)
      RETURN
C
   20 CONTINUE
C
C     DEBUGGING OUTPUT TEMPERATURES FOR FIRE B.C. CYCLE
C
      WRITE (NOUT,150) NCON
      WRITE (NOUT,230) (N,B(N),N=1,NUMNP)
      RETURN
C
   30 CONTINUE
C
C     OUTPUT DATA FOR DUMP WHEN PROBLEM HAS NOT CONVERGED AFTER
C     PERMISSIBLE NUMBER OF CYCLES
C
      WRITE (NOUT,160)
      WRITE (NOUT,170) MAIN,NCON
      WRITE (NOUT,180)
      WRITE (NOUT,230) (N,T1(N),N=1,NUMNP)
      WRITE (NOUT,190)
      WRITE (NOUT,230) (N,T(N),N=1,NUMNP)
      WRITE (NOUT,200)
      WRITE (NOUT,230) (N,B(N),N=1,NUMNP)
      STOP
C
   40 CONTINUE
```

```
C
C     OUTPUT OF RESULTS FOR A TIME STEP
C
      IF (II.EQ.1.OR.II.EQ.3) 50,60
   50 CONTINUE
C
C     OUTPUT NODAL POINT TEMPERTURES
C
      WRITE (NOUT,210)
      WRITE (NOUT,220)
      WRITE (NOUT,230) (N,T(N),N=1,NUMNP)
   60 CONTINUE
      IF (II.EQ.2.OR.II.EQ.3) 70,130
C
C     OUTPUT ELEMENT TEMPERATURES
C
C     ONE-DIMENSIONAL ELEMENTS
C
   70 IF (NEL1D.EQ.0) GO TO 90
      NLM=0
      WRITE (NOUT,240)
      WRITE (NOUT,220)
      DO 80 N=1,NEL1D
      NLM=NLM+2
      LL1=LM(NLM-1)
      LL2=LM(NLM)
   80 AT(N)=0.5*(T(LL1)+T(LL2))
      WRITE (NOUT,230) (N,AT(N),N=1,NEL1D)
C
C     TWO-DIMENSIONAL ELEMENTS
C
   90 IF (NEL2D.EQ.0) GO TO 110
      NLM=2*NEL1D
      WRITE (NOUT,250)
      WRITE (NOUT,220)
      DO 100 N=1,NEL2D
      NLM=NLM+4
      LL1=LM(NLM-3)
      LL2=LM(NLM-2)
      LL3=LM(NLM-1)
      LL4=LM(NLM)
  100 AT(N+NEL1D)=0.25*(T(LL1)+T(LL2)+T(LL3)+T(LL4))
      WRITE (NOUT,230) (N,AT(N+NEL1D),N=1,NEL2D)
C
C     THREE-DIMENSIONAL ELEMENTS
C
  110 IF (NEL3D.EQ.0) GO TO 130
      NLM=2*NEL1D+4*NEL2D
      WRITE (NOUT,260)
      WRITE (NOUT,220)
      DO 120 N=1,NEL3D
      NLM=NLM+8
      LL1=LM(NLM-7)
      LL2=LM(NLM-6)
      LL3=LM(NLM-5)
      LL4=LM(NLM-4)
      LL5=LM(NLM-3)
      LL6=LM(NLM-2)
      LL7=LM(NLM-1)
      LL8=LM(NLM)
      NI=N+NEL1D+NEL2D
  120 AT(NI)=0.125*(T(LL1)+T(LL2)+T(LL3)+T(LL4)+T(LL5)+T(LL6)+T(LL7)+T(L
     1L8))
      N2=NEL1D+NEL2D
      WRITE (NOUT,230) (N,AT(N+N2),N=1,NEL3D)
C
  130 RETURN
C
C
  140 FORMAT (/,62H  NODAL POINT TEMPERATURES AT BEGINNING OF SYSTEM CYC
     1LE NUMBER,I6/)
  150 FORMAT (/,40H  NODAL POINT TEMPERATURE FOR B.C. CYCLE,I5/)
  160 FORMAT (//,20H  PROGRAM TERMINATED,/,59H  CONVERGENCE NOT OBTAINED
     1 IN REQUIRED NUMBER OF ITERATIONS)
  170 FORMAT (/,15H  SYSTEM CYCLE ,I5,16H AND B.C. CYCLE ,I5)
  180 FORMAT (//,33H  SYSTEM NODAL POINT TEMPERATURES)
  190 FORMAT (//,53H  NODAL POINT TEMPERATURES AT BEGINNING OF B.C. CYCL
     1E)
  200 FORMAT (//,47H  NODAL POINT TEMPERATURES AT END OF B.C. CYCLE)
  210 FORMAT (//54H ------------ NODAL POINT TEMPERATURES --------------
     1-/)
  220 FORMAT (/1X,4(15H     N     TEMP. ))
  230 FORMAT (4(I6,F9.2))
  240 FORMAT (//,57H -------------- TEMPERATURE OF 1-D ELEMENTS --------
     1-----/)
  250 FORMAT (//,57H -------------- TEMPERATURE OF 2-D ELEMENTS --------
     1-----/)
  260 FORMAT (//,57H -------------- TEMPERATURE OF 3-D ELEMENTS --------
     1-----/)
      END
```

```
      SUBROUTINE PUOUT (I1,I2,T,AT,X,Y,Z,TIME,IP1,IP2,LM,JP)
C
C
C     SUBROUTINE *PUOUT* PUNCHES THE TEMPERATURE DISTRIBUTIONS THAT
C     RESULT FROM THE ANALYSIS DONE IN THE PROGRAM.
C        JP - IDENTIFIER TO BE USED IN LAST 8 COLUMNS
C        IP1 - COUNTER FOR NODAL DATA CARDS PUNCHED
C        IP2 - COUNTER FOR ELEMENT DATA CARDS PUNCHED
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNF,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION T(1), AT(1), X(1), Y(1), Z(1), LM(1)
      INTEGER ELEM
      NP=NELNCH
C
      IF (I2.EQ.1.OR.I2.EQ.3) 10,100
C
C     PUNCHING NODAL DATA
C
   10 WRITE (NOUT,240)
      NODE=4HNODE
      IF (JP.EQ.3H   ) GO TO 20
      ENCODE (4,250,NODE) JP
   20 CONTINUE
      IF (IP1.NE.0) GO TO 60
C
C     NODAL COORDINATES PUNCHED THE FIRST TIME TEMPERATURE DATA IS
C     REQUESTED
```

```
C
      IP1=IP1+1
      WRITE (NP,260) ITITLE,NODE,IP1
      IP1=IP1+1
      WRITE (NP,270) NODE,IP1
      IP1=IP1+1
      WRITE (NP,280) NODE,IP1
      N1=1
   30 N2=N1+2
      IP1=IP1+1
      IF (NUMNP-N2) 50,40,40
   40 WRITE (NP,290) (I,X(I),Y(I),Z(I),I=N1,N2),NODE,IP1
      IF (N2.EQ.NUMNP) GO TO 60
      N1=N2+1
      GO TO 30
   50 N2=NUMNP
      N=NUMNP+1-N1
      M=72-N*22
      ENCODE (30,300,L) N,M
      WRITE (NP,L) (I,X(I),Y(I),Z(I),I=N1,N2),NODE,IP1
C
C     PUNCHING NODAL POINT TEMPERATURES
C
   60 IP1=IP1+1
      WRITE (NP,310) TIME,NUMNP,NODE,IP1
      N1=1
   70 N2=N1+6
      IP1=IP1+1
      IF (NUMNP-N2) 90,80,80
   80 WRITE (NP,320) (I,T(I),I=N1,N2),NODE,IP1
      IF (N2.EQ.NUMNP) GO TO 100
      N1=N2+1
      GO TO 70
   90 N2=NUMNP
      N=NUMNP+1-N1
      M=72-N*10
      ENCODE (30,330,L) N,M
      WRITE (NP,L) (I,T(I),I=N1,N2),NODE,IP1
  100 IF (I2.EQ.2.OR.I2.EQ.3) 110,220
C
C     PUNCHING ELEMENT DATA
C
  110 WRITE (NOUT,340)
      IF (IP2.NE.0) GO TO 130
      ELEM=4HELEM
      IF (JP.EQ.3H   ) GO TO 120
      ENCODE (4,350,ELEM) JP
  120 CONTINUE
C
C     PUNCHING ELEMENT TEMPERATURES IN ORDER 1-D, 2-D, 3-D.
C
  130 IP2=IP2+1
      WRITE (NP,360) TIME,NUMEL,ELEM,IP2
      IF (I1.EQ.2.OR.I1.EQ.3) GO TO 190
C
C     CALCULATE THE AVERAGE ELEMENT TEMPERATURE
C
      IF (NEL1D.EQ.0) GO TO 150
      NLM=0
      DO 140 N=1,NEL1D
      NLM=NLM+2
      II1=LN(NLM-1)
      LL2=LM(NLM)
  140 AT(N)=0.5*(T(LL1)+T(LL2))
  150 IF (NEL2D.EQ.0) GC TO 170
      NLM=2*NEL1D
      DO 160 N=1,NEL2C
      NLM=NLM+4
      LL1=LM(NLM-3)
      LL2=LM(NLM-2)
      LL3=LM(NLM-1)
      LL4=LM(NLM)
  160 AT(N+NEL1D)=0.25*(T(LL1)+T(LL2)+T(LL3)+T(LL4))
  170 IF (NEL3D.EQ.0) GO TO 190
      NLM=2*NEL1D+4*NEL2D
      DO 18C N=1,NEL3D
      NLM=NLM+8
      LL1=LM(NLM-7)
      LL2=LM(NLM-6)
      LL3=LM(NLM-5)
      LL4=LM(NLM-4)
      LL5=LM(NLM-3)
      LL6=LM(NLM-2)
      LL7=LM(NLM-1)
      LL8=LM(NLM)
      N1=N+NEL1D+NEL2D
  180 AT(N1)=.125*(T(LL1)+T(LL2)+T(LL3)+T(LL4)+T(LL5)+T(LL6)+T(LL7)+T(LL
     18))
C
  150 CONTINUE
      N1=1
  200 N2=N1+6
      IP2=IP2+1
      IF (NUMEL-N2) 22C,210,21C
  210 WRITE (NP,320) (I,AT(I),I=N1,N2),ELEM,IP2
      IF (N2.EQ.NUMEL) GO TO 230
      N1=N2+1
      GO TC 200
  220 N2=NUMEL
      N=NUMEL+1-N1
      M=72-N*10
      ENCODE (30,330,L) N,M
      WRITE (NP,L) (I,AT(I),I=N1,N2),ELEM,IP2
  230 CONTINUE
C
      RETURN
C
C
  240 FORMAT (//,37H  . . . . PUNCHING NODAL DATA . . . .)
  250 FORMAT (1HN,A3)
  260 FORMAT (7A10,A2,A4,I4)
  270 FORMAT (52H  NODAL POINT TEMPERATURES FOR SELECT TIME INTERVALS,20
     1X,A4,I4)
  280 FORMAT (40H  NODAL POINT COORDINATES - NUMBER,X,Y,Z,32X,A4,I4)
  290 FORMAT (3(I4,3F6.3),6X,A4,I4)
  300 FORMAT (1H(,I1,11H(I4,3F6.3),,I2,8HX,A4,I4))
  310 FORMAT (41H  ----NODAL POINT TEMPERATURES AT TIME = ,F7.3,3H - ,I3
     1,6H NODES,12X,A4,I4)
  320 FORMAT (7(I4,F6.1),2X,A4,I4)
  330 FORMAT (1H(,I1,10H(I4,F5.1),,I2,8HX,A4,I4))
  340 FORMAT (//,39H  . . . . PUNCHING ELEMENT DATA . . . .)
  350 FORMAT (1HE,A3)
  360 FORMAT (37H  ----ELEMENT TEMPERATURES AT TIME = ,F7.3,3H - ,I3,9H
     1ELEMENTS,13X,A4,I4)
```

```
      END
```

```
      SUBROUTINE FIREMAT (MAT,FXYS,NSTORE)
C
C
C     SUBROUTINE *FIREMAT* INPUTS THE VARIABLES REQUIRED IN THE
C     ASSESSMENT OF THE HEAT FLOW ASSOCIATED WITH BOTH LINEAR AND
C     NON-LINEAR FIRE BOUNDARY CONDITIONS
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      DIMENSION MAT(1), FXYS(1)
C
C     OUTPUT PAGE HEADING
C
      WRITE (NOUT,40)
      WRITE (NOUT,50)
      WRITE (NOUT,60) ITITLE
C
      IF (NBCTYP.EQ.10HLINEAR BC ) GO TO 20
C
C     NON-LINEAR FIRE BOUNDARY CONDITION
C
      WRITE (NOUT,70)
      WRITE (NOUT,50)
      WRITE (NOUT,80)
      READ (NIN,90) SB,TSHIFT
      WRITE (NOUT,100) SB,TSHIFT
      WRITE (NOUT,110)
C
      FXYS(1)=SB
      FXYS(2)=TSHIFT
      NSTORE=3
C
C     INPUT DIFFERENT MATERIAL PROPERTIES FOR FIRE BC
C
      DO 10 I=1,NBCMAT
      MAT(I)=NSTORE
      READ (NIN,90) A,P,V,AB,EF,ES
      WRITE (NOUT,120) I,A,P,V,AB,EF,ES
      FXYS(NSTORE)=A
      FXYS(NSTORE+1)=P
      FXYS(NSTORE+2)=V
      FXYS(NSTORE+3)=AB
      FXYS(NSTORE+4)=EF
      FXYS(NSTORE+5)=ES
      NSTORE=NSTORE+6
   10 CONTINUE
      RETURN
C
   20 CONTINUE
C
C     LINEAR FIRE BOUNDARY CONDITION
C
      WRITE (NOUT,130)
      WRITE (NOUT,50)
      WRITE (NOUT,140)
```

```
C
      NSTORE=1
      DO 30 I=1,NBCMAT
      WRITE (NOUT,150) I
      READ (NIN,160) K
      MS=(I-1)*2
      MAT(MS+1)=NSTORE
      MAT(MS+2)=K
C
      CALL MATIN (K,FXYS(NSTORE),FXYS(NSTORE+K),FXYS(NSTORE+K+K))
C
      NSTORE=NSTORE+3*K
      IF (K.EQ.0) NSTORE=NSTORE+1
   30 CONTINUE
C
      RETURN
C
C
   40 FORMAT (1H6,5(/))
   50 FORMAT (61H ******************************************************
     1******)
   60 FORMAT (/5X50HFIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL,/
     1/1X,6A10)
   70 FORMAT (/5X,34HNON-LINEAR FIRE BOUNDARY CONDITION,/)
   80 FORMAT (//1X,60HQ=A*(TF-TS)**N+SB*V*(AB*EF*(TF+TSHIFT)**4-ES*(TS+T
     1SHIFT)**4))
   90 FORMAT (8E10.0)
  100 FORMAT (//1X,5HWHERE/6X,28HTF - PSUEDU FIRE TEMPERATURE,/6X,24HTS
     1- SURFACE TEMPERATURE,/6X,33HSB - STEFAN BOLZTMANN CONSTANT = ,E12
     2.4/6X,47HTSHIFT - SHIFT TO ABSOLUTE TEMPERATURE SCALE = ,F8.1/1X,3
     3HAND)
  110 FORMAT (//58H MAT  CONVECT  CONVECT     VIEW  ABSORBT     FIRE  SU
     1RFACE,/58H NUM   FACTOR    POWER   FACTOR            EMISSIV  EMISS
     2IV,/10X,3H(A),6X,3H(N),6X,3H(V),5X,4H(AB),5X,4H(EF),5X,4H(ES))
  120 FORMAT (/I4,6F9.3)
  130 FORMAT (/5X,30HLINEAR FIRE BOUNDARY CONDITION,/)
  140 FORMAT (//9X,16HQ = H(T)*(TF-TS)//10X,5HWHERE,/15X,31HH(T) - HEAT
     1TRANSFER COEFFICENT,/15X,28HTF - PSUEDO FIRE TEMPERATURE,/15X,24HT
     2S - SURFACE TEMPERATURE,/15X,33HT - AVERAGE TEMPERATUTE (TF+TS)/2,
     3//)
  150 FORMAT (//,25H    . . . MATERIAL NUMBER ,I4,6H . . .)
  160 FORMAT (I5)
      END


      SUBROUTINE FIREBC (X,Y,Z,KODE,BAREA,THICK,LI,LJ,LK,LL,LMAT,LFIRE,A
     1IJKL,LELEM)
C
C
C     SUBROUTINE *FIREBC* INPUTS THE GEOMETRIC DESCRIPTION OF THE
C     SURFACE OF THE SYSTEM THAT WILL BE DIRECTLY EXPOSED TO THE
C     FIRE ENVIRONMENT
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,NBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NHCMAT,NHCTYP
      COMMON /SURFACE/ NS1,NS2,NS3
      DIMENSION X(1), Y(1), KODE(1), LI(1), LJ(1), LMAT(1), LFIRE(1), Z(
     11), LK(1), LL(1), AIJKL(1), BAREA(1), THICK(1), LELEM(1)
```

```
C
      DO 70 I=I1,I2
      IF (LMAT(I).GT.NBCMAT) GO TO 80
      II=LI(I)
      JJ=LJ(I-NFBC1D)
      IF (KODE(II).EQ.4HTEMP.OR.KODE(JJ).EQ.4HTEMP) GO TO 80
   70 CONTINUE
      GO TO 90
C
   80 IO=I-NFBC1D
      WRITE (NOUT,280) IO,LI(I),LJ(IO),LMAT(I),LFIRE(I),LELEM(I)
      STOP
C
C     CALCULATE AREA OF FIRE B.C. SURFACE ELEMENT
C
   90 CONTINUE
      DO 100 I=I1,I2
      II=LI(I)
      JJ=LJ(I-NFBC1D)
      DX=X(II)-X(JJ)
      DY=Y(II)-Y(JJ)
      DZ=Z(II)-Z(JJ)
      D=DX*DX+DY*DY+DZ*DZ
      IK=LELEM(I)
  100 AIJKL(I)=SQRT(D)*THICK(IK)
C
C     OUTPUT SURFACE ELEMENT DATA
C
      WRITE (NOUT,300)
      WRITE (NOUT,330) (I,LI(I+NFBC1D),LJ(I),LMAT(I+NFBC1D),LFIRE(I+NFBC
     11D),AIJKL(I+NFBC1D),I=1,NS2)
C
C     REDUCE AREA TO 1/2 FOR FUTURE CALCULATIONS
C
      DO 110 I=I1,I2
  110 AIJKL(I)=AIJKL(I)/2.
C
C     T H R E E - D I M E N S I O N A L   E L E M E N T S
C
  120 IF (NS3.EQ.0) GO TO 190
      WRITE (NOUT,220) NS3
C
C     INPUT FIRE B.C. DATA  -  TWO ELEMENTS PER CARD
C
      I1=NFBC1D+NFBC2D+1
      I2=NFBC1D+NFBC2D+NS3
      N1=NFBC1D+NFBC2D
      READ (NIN,230) (LI(I),LJ(I-NFBC2D),LK(I-N1),LL(I-N1),LMAT(I),LFIRE
     1(I),I=I1,I2)
C
C     CHECK VALIDITY OF MATERIAL REQUIREMENTS AND PREVIOUSLY DECLARED
C     BOUNDARY CONDITIONS.  FOR A SURFACE TO BE CONSIDERED A FIRE B.C.
C     IT MUST BE BOUNDED BY NODES THAT HAVE A DECLARED FLOW B.C.
C
      DO 130 I=1,NS3
      IF (LMAT(I+N1).GT.NBCMAT) GO TO 140
      II=LI(I+N1)
      JJ=LJ(I+NFBC2D)
      KK=LK(I)
      LLL=LL(I)
      IF (KODE(II).EQ.4HTEMP.OR.KODE(JJ).EQ.4HTEMP) GO TO 140
      IF (KODE(KK).EQ.4HTEMP.OR.KODE(LLL).EQ.4HTEMP) GO TO 140
  130 CONTINUE
      GO TO 150
C
  140 CONTINUE
      WRITE (NOUT,260) I,LI(I+N1),LJ(I+NFBC2D),LK(I),LL(I),LMAT(I+N1),LF
     1IRE(I+N1)
      STOP
C
C     CALCULATE THE  AREA  OF THE FIRE BC SURFACE ELEMENTS
C
  150 CONTINUE
      DO 170 I=1,NS3
      II=LI(I+N1)
      JJ=LJ(NFBC2D+I)
      KK=LK(I)
      DX=X(II)-X(JJ)
      DY=Y(II)-Y(JJ)
      DZ=Z(II)-Z(JJ)
      D=DX*DX+DY*DY+DZ*DZ
      XL1=SQRT(D)
      DX=X(JJ)-X(KK)
      DY=Y(JJ)-Y(KK)
      DZ=Z(JJ)-Z(KK)
      D=DX*DX+DY*DY+DZ*DZ
      XL2=SQRT(D)
      AIJKL(I+N1)=XL1*XL2
      IF (LK(I)-LL(I)) 170,160,170
  160 AIJKL(I+N1)=0.5*AIJKL(I+N1)
  170 CONTINUE
C
C     OUTPUT SURFACE ELEMENT DATA
C
      WRITE (NOUT,310)
      WRITE (NOUT,340) (I,LI(I+N1),LJ(I+NFBC2D),LK(I),LL(I),LMAT(I+N1),L
     1FIRE(I+N1),AIJKL(I+N1),I=1,NS3)
C
C     REDUCE THE SURFACE  AREA  BY 1/4 TO AID IN FUTURE COMPUTATION
C
      DO 180 I=I1,I2
  180 AIJKL(I)=.25*AIJKL(I)
C
  190 RETURN
C
C
C
  200 FORMAT (////16H . . . THERE ARE,I4,40H 1-D SURFACE NODES EXPOSED T
     1O FIRE . . .)
  210 FORMAT (////16H . . . THERE ARE,I4,41H 2-D SURFACE ELEMENTS EXPOSE
     1D TO FIRE . .)
  220 FORMAT (////16H . . . THERE ARE,I4,41H 3-D SURFACE ELEMENTS EXPOSE
     1D TO FIRE . .)
  230 FORMAT (12I5)
  240 FORMAT (16I5)
  250 FORMAT (15I5)
  260 FORMAT (5(/),54H  - - - PROGRAM TERMINATED - FIRE BC INPUT ERROR -
     1 - -,1X,7I5)
  270 FORMAT (5(/),54H  - - - PROGRAM TERMINATED - FIRE BC INPUT ERROR -
     1 - -,1X,5I5)
  280 FORMAT (5(/),54H  - - - PROGRAM TERMINATED - FIRE BC INPUT ERROR -
     1 - -,1X,6I5)
  290 FORMAT (//9X,47HDESCRIPTION OF SURFACE DIRECTLY EXPOSED TO FIRE,//
     138H FIREBC   NODE    MAT    FIRE       AREA/2PI SURFACE      I    TYPE
     2   TYPE/)
  300 FORMAT (//9X,47HDESCRIPTION OF SURFACE DIRECTLY EXPOSED TO FIRE,//
     145H FIREBC    NODE    NODE     MAT    FIRE        AREA/35H SURFACE      I
     2        J    TYPE    TYPE/)
  310 FORMAT (//9X,47HDESCRIPTION OF SURFACE DIRECTLY EXPOSED TO FIRE,//
     159H FIREBC    NODE    NODE    NODE    NODE     MAT    FIRE        AREA/49H
     2 SURFACE      I        J        K        L    TYPE    TYPE/)
  320 FORMAT (4I7,F10.3)
  330 FORMAT (5I7,F10.3)
  340 FORMAT (7I7,F10.3)
  350 FORMAT (80R1)
  360 FORMAT (6(/),45H - - - PROGRAM TERMINATED - INPUT ERROR - - -,//1X
     1,80R1)
      END



      SUBROUTINE FIRE (LI,LJ,LK,LL,LMAT,LFIRE,AIJKL,MAT,FXYS,T,TFIRE,B)
C
C
C     SUBROUTINE *FIRE* CALCULATES THE HEAT FLOW ASSOCIATED WITH A FIRE
C     REPRESENTED THROUGH TEMPERATURES TFIRE(I).  THESE HEAT FLOWS
C     ARE DETERMINED UPON THE BASIS OF THE ASSUMED TEMPERATURE VECTOR T.
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      COMMON /SURFACE/ NS1,NS2,NS3
      DIMENSION LI(1), LJ(1), LMAT(1), LFIRE(1), AIJKL(1), MAT(1), FXYS(
     11), T(1), TFIRE(1), TF4(4), B(1), LK(1), LL(1)
C
C     IF BOUNDARY CONDITION IS NONLINEAR TAKE FIRE TEMPERATURES TO
C     THEIR FOURTH POWERS
C
      IF (NBCTYP.EQ.10HLINEAR BC ) GO TO 20
      SB=FXYS(1)
      TSHIFT=FXYS(2)
      DO 10 I=1,4
      TF=TFIRE(I)+TSHIFT
      TF =TF*TF
   10 TF4(I)=TF*TF
C
C     O N E - D I M E N S I O N A L   E L E M E N T S
C
   20 IF (NS1.EQ.0) GO TO 40
      DO 30 N=1,NS1
C
C     ESTABLISH BASIC FIRE B.C. VARIABLES FOR THIS SURFACE ELEMENT
C
      N3=N
      I=LI(N)
      M=LMAT(N)
      LF=LFIRE(N)
      TF=TFIRE(LF)
      TS=T(I)
C
C     FIND HEAT FLOW DUE TO FIRE B.C.
C
      Q=QFIRE(TF,TS,LF,NBCTYP,M,N3,TSHIFT,SB,TF4,MAT,FXYS,AIJKL)
C
```

```
C     ADD HEAT FLOW TO NODES BOUNDING SURFACE ELEMENT
C
      B(I)=B(I)+Q
   30 CONTINUE
C
C     T W O - D I M E N S I O N A L   E L E M E N T S
C
   40 IF (NS2.EQ.0) GO TO 60
      DO 50 N=1,NS2
C
C     ESTABLISH BASIC FIRE B.C. VARIABLES FOR THIS SURFACE ELEMENT
C
      N3=N+NFBC1D
      I=LI(N3)
      J=LJ(N)
      M=LMAT(N3)
      LF=LFIRE(N3)
      TF=TFIRE(LF)
      TS=0.5*(T(I)+T(J))
C
C     FIND HEAT FLOW DUE TO FIRE B.C.
C
      Q=QFIRE(TF,TS,LF,NBCTYP,M,N3,TSHIFT,SB,TF4,MAT,FXYS,AIJKL)
C
C     ADD HEAT FLOW TO NODES BOUNDING SURFACE ELEMENT
C
      B(I)=B(I)+Q
      B(J)=B(J)+Q
   50 CONTINUE
C
C     T H R E E - D I M E N S I O N A L   E L E M E N T S
C
   60 IF (NS3.EQ.0) GO TO 80
      DO 70 N=1,NS3
C
C     ESTABLISH BASIC FIRE B.C. VARIABLES FOR THIS SURFACE ELEMENT
C
      N3=N+NFBC1D+NFBC2D
      I=LI(N3)
      J=LJ(N+NFBC2D)
      NK=LK(N)
      NL=LL(N)
      M=LMAT(N3)
      LF=LFIRE(N3)
      TF=TFIRE(LF)
      TS=.25*(T(I)+T(J)+T(NK)+T(NL))
C
C     FIND HEAT FLOW DUE TO FIRE B.C.
C
      Q=QFIRE(TF,TS,LF,NBCTYP,M,N3,TSHIFT,SB,TF4,MAT,FXYS,AIJKL)
C
C     ADD HEAT FLOW TO NODES BOUNDING SURFACE ELEMENT
C
      B(I)=B(I)+Q
      B(J)=B(J)+Q
      B(NK)=B(NK)+Q
      B(NL)=B(NL)+Q
   70 CONTINUE
C
   80 RETURN
      END
      FUNCTION QFIRE (TF,TS,LF,NBCTYP,N,N3,TSHIFT,SB,TF4,MAT,FXYS,AIJKL)
C
C
C     FUNCTION *QFIRE* FINDS HEAT FLOW DUE TO FIRE ON SURFACE ELEMENT
C
C
      DIMENSION TF4(1), MAT(1), FXYS(1), AIJKL(1)
C
C
      DT=TF-TS
      IF (NBCTYP.EQ.10HNON-LIN BC) GO TO 10
C
C     LINEAR FIRE BOUNDARY CONDITION
C
      M=(N-1)*2
      JJ=MAT(M+1)
      K=MAT(M+2)
      TA=0.5*(TF+TS)
      H=VMAT(K,FXYS(JJ),FXYS(JJ+K),FXYS(JJ+K+K),TA,10H  H(T)     )
      Q=AIJKL(N3)*H*DT
      GO TO 50
C
   10 CONTINUE
C
C     NON-LINEAR FIRE BOUNDARY CONDITION
C
      K=MAT(N)
      A=FXYS(K)
      QC=0.0
      IF (A.EQ.0) GO TO 30
C
C     CALCULATE CONVECTION TERM - QC
C
      P=FXYS(K+1)
      IF (P.EQ.1.0) GO TO 20
      SIGN=1.0
      IF (DT.LT.0) SIGN=-1.0
      DT=SIGN*DT
      QC=SIGN*A*DT**P
      GO TO 30
   20 QC=A*DT
   30 V=FXYS(K+2)
      QR=0.0
      IF (V.EQ.0) GO TO 40
C
C     CALCULATE RADIATION TERM - QR
C
      TS=TS+TSHIFT
      TS=TS*TS
      TS=TS*TS
      AB=FXYS(K+3)
      EF=FXYS(K+4)
      ES=FXYS(K+5)
      QR=SB*V*(AB*EF*TF4(LF)-ES*TS)
   40 Q=AIJKL(N3)*(QC+QR)
   50 QFIRE=Q
      RETURN
C
      END
      SUBROUTINE EXOELS (X,Y,Z,LM,BAREA,THICK,VOLUME,IEL,IMAT,VEL)
C
C
C     SUBROUTINE *EXOELS* INPUTS DATA DESCRIBING ALL ELEMENTS WHICH HAVE
C     INTERNAL HEAT GENERATION
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      COMMON /EXOTH/ NINT1D,NINT2D,NINT3D,NINT,NCINT
      DIMENSION X(1), Y(1), Z(1), LM(1), BAREA(1), THICK(1), VOLUME(1),
     1IEL(1), IMAT(1), VEL(1)
C
C     O N E - D I M E N S I O N A L   E L E M E N T S
C
      IF (NINT1D.EQ.0) GO TO 20
C
C     INPUT 1-D ELEMENTS WITH INTERNAL HEAT GENERATION - 8 ELEMENTS/CARD
C
      READ (NIN,70) (IEL(I),IMAT(I),I=1,NINT1D)
C
C     FIND VOLUME OF ELEMENTS AND OUTPUT DATA
C
      DO 10 N=1,NINT1D
      IE=IEL(N)
      II=LM(2*IE-1)
      JJ=LM(2*IE)
      DX=X(II)-X(JJ)
      DY=Y(II)-Y(JJ)
      DZ=Z(II)-Z(JJ)
      DL=SQRT(DX*DX+DY*DY+DZ*DZ)
   10 VEL(N)=DL*BAREA(IE)
      WRITE (NOUT,80) NINT1D
      WRITE (NOUT,90) (I,IEL(I),IMAT(I),VEL(I),I=1,NINT1D)
C
C     T W O - D I M E N S I O N A L   E L E M E N T S
C
   20 IF (NINT2D.EQ.0) GO TO 40
C
C     INPUT 2-D ELEMENTS WITH INTERNAL HEAT GENERATION - 8 ELEMENTS/CARD
C
      I1=NINT1D+1
      I2=NINT1D+NINT2D
      READ (NIN,70) (IEL(I),IMAT(I),I=I1,I2)
C
C     FIND VOLUME OF ELEMENTS AND OUTPUT DATA
C
      DO 30 N=I1,I2
      IE=IEL(N)
      IARG=2*NEL1D+4*IE-3
      II=LM(IARG)
      JJ=LM(IARG+1)
      KK=LM(IARG+2)
      LL=LM(IARG+3)
      AJ=X(JJ)-X(II)
      AK=X(KK)-X(II)
      BJ=Y(JJ)-Y(II)
      BK=Y(KK)-Y(II)
      AREA=(AJ*BK-AK*BJ)/2.
      AJ=X(KK)-X(II)
      AK=X(LL)-X(II)
      BJ=Y(KK)-Y(II)
      BK=Y(LL)-Y(II)
      AREA=AREA+(AJ*BK-AK*BJ)/2.
   30 VEL(N)=AREA*THICK(IF)
      WRITE (NOUT,100) NINT2D
      WRITE (NOUT,90) (I,IEL(I+NINT1D),IMAT(I+NINT1D),VEL(I+NINT1D),I=1,
     1NINT2D)
C
C     T H R E E - D I M E N S I O N A L   E L E M E N T S
C
   40 IF (NINT3D.EQ.0) GO TO 60
C
C     INPUT 3-D ELEMENTS WITH INTERNAL HEAT GENERATION - 8 ELEMENTS/CARD
C
      I1=NINT1D+NINT2D+1
      I2=NINT
      READ (NIN,70) (IEL(I),IMAT(I),I=I1,I2)
C
C     FIND VOLUME OF ELEMENTS AND OUTPUT DATA
C
      DO 50 N=I1,I2
      IE=IEL(N)
   50 VEL(N)=VOLUME(IE)
      N1=NINT1D+NINT2D
      WRITE (NOUT,110) NINT3D
      WRITE (NOUT,90) (I,IEL(I+N1),IMAT(I+N1),I=1,NINT2D)
C
C
   60 RETURN
C
C
C
C
   70 FORMAT (8(2I5))
   80 FORMAT (///9X,16H. . . THERE ARE ,I4,28H 1-D EXOTHERMIC ELEMENTS .
     1 .//2(30H            N    EL   FUN     VOLUME))
   90 FORMAT (2(I10,2I5,F10.4))
  100 FORMAT (///9X,16H. . . THERE ARE ,I4,28H 2-D EXOTHERMIC ELEMENTS .
     1 .//2(30H            N    EL   FUN     VOLUME))
  110 FORMAT (///9X,16H. . . THERE ARE ,I4,28H 3-D EXOTHERMIC ELEMENTS .
     1 .//2(30H            N    EL   FUN     VOLUME))
      END
```

```
      SUBROUTINE EXOFUN (IEXO,EXYS,NSTORE)
C
C
C     SUBROUTINE *EXOFUN* INPUTS THE EXOTHERMIC HEAT GENERATION CURVE
C     AS A LINEARIZED FUNCTION OF TIME
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNP,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NEBC1D,NEBC2D,NEBC3D,NBCMAT,NBCTYP
      COMMON /EXOTH/ NINT1D,NINT2D,NINT3D,NINT,NCINT
      DIMENSION IEXO(1), EXYS(1)
      NSTORE=1
C
C     OUTPUT PAGE HEADING
C
      WRITE (NOUT,40)
      WRITE (NOUT,50)
      WRITE (NOUT,60) ITITLE
      WRITE (NOUT,70) NQINT
      WRITE (NOUT,50)
C
      DO 30 N=1,NQINT
C
C     READ CONTROL CARD
C
C        NSTORE = IEXO(1) - STARTING POINT FOR FUNCTION N IN EXYS
C        MK = IEXO(2) - NUMBER OF POINTS IN INPUT HEATING CURVE
C        MT = IEXO(3) - TYPE OF INPUT HEATING DATA
C                       EQ. 0 - HEAT RATE PER UNIT VOLUME
C                       EQ. 1 - HEAT RATE PER UNIT MASS
C
      WRITE (NOUT,110) N
      READ (NIN,120) MK,MT
      MS=(N-1)*3
      IEXO(MS+1)=NSTORE
      IEXO(MS+2)=MK
      IEXO(MS+3)=MT
C
C     INPUT HEATING FUNCTION
C
      N1=NSTORE-1
      READ (NIN,130) (EXYS(N1+I),EXYS(N1+MK+I),I=1,MK)
      M=MK-1
C
C     DETERMINE SLOPES AND PRINT HEATING FUNCTION
C
      DO 10 I=1,M
      N1=NSTORE+I-1
   10 EXYS(N1+MK+MK)=(EXYS(N1+MK+1)-EXYS(N1+MK))/(EXYS(N1+1)-EXYS(N1))
      WRITE (NOUT,80)
      DO 20 I=1,M
      N1=NSTORE+I-1
      WRITE (NOUT,90) I,EXYS(N1),EXYS(N1+MK)
   20 WRITE (NOUT,100) EXYS(N1+MK+MK)
      WRITE (NOUT,90) MK,EXYS(NSTORE+MK-1),EXYS(NSTORE+MK+MK-1)
      NSTORE=NSTORE+3*MK
   30 CONTINUE
      RETURN
C
C
C
C
   40 FORMAT (1H6,5(/))
   50 FORMAT (61H ******************************************************
     1******)
   60 FORMAT (/5X50HFIRES-T3  -  FIRE RESPONSE OF STRUCTURES - THERMAL,/
     1/1X,6A10)
   70 FORMAT (/5X,36HINTERNAL HEAT GENERATION INFORMATION,//5X,9HTHERE A
     1RE,I4,25H DIFFERENT HEAT FUNCTIONS/)
   80 FORMAT (/5X,19HNODE              TIME,6X,5H HEAT,7X,5HSLOPE,/)
   90 FORMAT (I9,F13.1,6X,G11.3)
  100 FORMAT (39X,G11.3)
  110 FORMAT (////,26H ´. . . . FUNCTION NUMBER ,I4,9H  . . . ./)
  120 FORMAT (2I5)
  130 FORMAT (8E10.0)
      END
      SUBROUTINE QEXO (LM,IEL,IMAT,IEXO,EXYS,AT,MATL,VEL,MMTYPE,B,XYS,TI
     1ME)
C
C
C      SUBROUTINE *QEXO* COMPUTES NODAL HEAT FLOW DUE TO EXOTHERMIC
C      REACTION WITHIN ELEMENTS
C
C
      COMMON /CONTROL/ ITITLE(6),IREAD(80),NIN,NOUT,NPUNCH,NUMNF,NEL1D,N
     1EL2D,NEL3D,NUMEL,MBAND,NMAT,NFBC1D,NFBC2D,NFBC3D,NBCMAT,NBCTYP
      COMMON /EXOTH/ NINT1D,NINT2D,NINT3D,NINT,NCINT
      DIMENSION LM(1), IEL(1), IMAT(1), IEXO(1), EXYS(1), AT(1), MATL(1)
     1, VEL(1), MMTYPE(1), B(1), XYS(1)
C
C      O N E - D I M E N S I O N A L   E L E M E N T S
C
      IF (NINT1D.EQ.0) GO TO 30
      DO 20 N=1,NINT1D
      IE=IEL(N)
      II=LM(2*IE-1)
      JJ=LM(2*IE)
      MS=IMAT(N)
      MS=3*(MS-1)
      J=IEXO(MS+1)
      K=IEXO(MS+2)
      LTYPE=IEXO(MS+3)
      Q=VMAT(K,EXYS(J),EXYS(J+K),EXYS(J+K+K),TIME,10HHEAT FUNCT)
      IF (LTYPE.EQ.0) GO TO 10
      TEMP=AT(IE)
      MS=MMTYPE(IE)
      MS=(MS-1)*6
      J=MATL(MS+5)
      K=MATL(MS+6)
      DENS=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H      DENS)
      Q=Q*DENS
   10 QADD=Q*VEL(N)/2.
      B(II)=B(II)+QADD
   20 B(JJ)=B(JJ)+QADD
C
C      T W O - D I M E N S I O N A L   E L E M E N T S
C
   30 IF (NINT2D.EQ.0) GO TO 60
      I1=NINT1D+1
      I2=NINT1D+NINT2D
      DO 50 N=I1,I2
      IE=IEL(N)
      N1=2*NEL1D+4*IE
      II=LM(N1-3)
      JJ=LM(N1-2)
      KK=LM(N1-1)
      LL=LM(N1)
      MS=IMAT(N)
      MS=3*(MS-1)
      J=IEXO(MS+1)
      K=IEXO(MS+2)
      LTYPE=IEXO(MS+3)
      Q=VMAT(K,EXYS(J),EXYS(J+K),EXYS(J+K+K),TIME,10HHEAT FUNCT)
      IF (LTYPE.EQ.0) GO TO 40
      TEMP=AT(NEL1D+IE)
      MS=MMTYPE(NEL1D+IE)
      MS=(MS-1)*6
      J=MATL(MS+5)
      K=MATL(MS+6)
      DENS=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H      DENS)
      Q=Q*DENS
   40 QADD=Q*VEL(N)/4.
      B(II)=B(II)+QADD
      B(JJ)=B(JJ)+QADD
      B(KK)=B(KK)+QADD
   50 B(LL)=B(LL)+QADD
C
C     T H R E E - D I M E N S I O N A L   E L E M E N T S
C
   60 IF (NINT3D.EQ.0) GO TO 90
      I1=NINT1D+NINT2D+1
      I2=NINT
      DO 80 N=I1,I2
      IE=IEL(N)
      N1=2*NEL1D+4*NEL2D+8*IE
      II=LM(N1-7)
      JJ=LM(N1-6)
      KK=LM(N1-5)
      LL=LM(N1-4)
      III=LM(N1-3)
      JJJ=LM(N1-2)
      KKK=LM(N1-1)
      LLL=LM(N1)
      MS=IMAT(N)
      MS=(MS-1)*3
      J=IEXQ(MS+1)
      K=IEXQ(MS+2)
      LTYPE=IEXQ(MS+3)
      Q=VMAT(K,EXYS(J),EXYS(J+K),EXYS(J+K+K),TIME,10HHEAT FUNCT)
      IF (LTYPE.EQ.0) GO TO 70
      TEMP=AT(NEL1D+NEL2D+IE)
      MS=MMTYPE(NEL1D+NEL2D+IE)
      MS=(MS-1)*6
      K=MATL(MS+6)
      J=MATL(MS+5)
      DENS=VMAT(K,XYS(J),XYS(J+K),XYS(J+K+K),TEMP,10H      DENS)
      Q=Q*DENS
   70 QADD=Q*VEL(N)/8.
      B(II)=B(II)+QADD
      B(JJ)=B(JJ)+QADD
      B(KK)=B(KK)+QADD
      B(LL)=B(LL)+QADD
      B(III)=B(III)+QADD
      B(JJJ)=B(JJJ)+QADD
      B(KKK)=B(KKK)+QADD
   80 B(LLL)=B(LLL)+QADD
C
   90 RETURN
      END
```

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Iding, R., Bresler, B., and Nizamuddin
Department of Civil Engineering
University of California, Berkeley, CA

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This report documents the computer program FIRES-T3 (Fire Response of Structures – Thermal – Three-Dimensional Version). The program evaluates the temperature distribution history of general three-dimensional solids or composites such as reinforced concrete subjected to fire environments. There are also options of two-dimensional and one-dimensional heat flow analyses. FIRES-T3 is based on a finite element formulation which considered the temperature dependence of thermal properties and the nonlinearities inherent in modeling the fire boundary condition. The finite element formulation, the idealization of the fire boundary condition, and the general numerical approach used in the program are discussed. Included in the report are appendices that provide input instructions for FIRES-T3, sample problems with listings of their input and output, and a complete Fortran listing of the computer program.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

computer modes; concrete slabs; fire models; heat transfer; steel structures; structural design

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